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Chemical Engineering

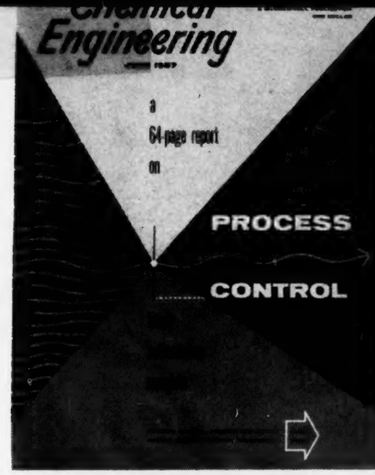
A McGRAW-HILL PUBLICATION
ONE DOLLAR

JUNE 1957

a 72-page report on

PROCESS CONTROL

timely
authoritative
complete



JUNE 1957

JOHN R. CALLAHAM, Editor-in-Chief

Easier to Find, Read, File

Some of the things we're doing to make CE easier for you to use:

▶**Easier to Find:** Our contents pages—always just inside the front cover—have more complete listings, more descriptive titles, better organization than ever before.

All editorial is now organized, for quick reference, into four major sections . . . Developments, Practice, People, Reader Service.

A new contents page for each section makes it easier to spot, within seconds, items of immediate interest; two-line squibs flash the gist of each story.

▶**Easier to Read:** Mixing of ads and editorial *on the same page* has been eliminated from more than the first half of the book (first "mixed" page in this issue is p. 360. No other chemical publication can say the same.

There are no "continued-in-the-back" features; nowhere do you have to turn more than a page or so to continue any story.

Three-line interpretations at the start of each feature tell at a glance what it's about, why it's important; lead-off paragraphs pick up to orient and put into perspective.

Style has been quickened, made more readable, more informal . . . charts, graphs and tables are designed to show glance-level meaning.

▶**Easier to File:** Department pages are now faced by ads, can be clipped without destroying other editorial . . . 100% fileability.

More feature articles start on the right, end on the left . . . can be filed intact. Three years ago 24% of our features could be clipped without damaging other articles. Today it's close to 75%—and we're still working at it!

GUIDED TOUR

Process control enters a new era

Keeping you informed of the newest concepts of process control is our aim in this special 72-page report. How today's developments in maximized control . . . coupled with new analytical devices and computers . . . is leading to optimized control. Promise of the future—fully automatic control. (p. 249)

Find process instrument elements

For quick and handy reference, use our expanded and revised guide. Basic information helps you select the necessary methods or devices to measure, transmit and control all process variables. (p. 287)

Quick way to optimum conditions

Important new statistical tool takes the path of steepest ascent to get optimum

GUIDED TOUR

process conditions. It cuts down on experiments, saves time and money in pilot-plant or full-scale development work. (p. 238)

New kinks on chlorine recovery

Bothered by chlorine "sniff gas"? If so, here're two brand new and efficient ways to stave off a pollution headache—and make a profit at it to boot. (p. 154)

Tonnage minerals, tonnage chemicals

Today's trend toward chemical processing of ores is something you can't afford to overlook. Here, for the first time anywhere, are chemical figures straight from on-the-spot contact with users. (p. 200)

You're becoming more valuable

As chemical engineering enrollments continue to lose ground, you'll be harder to replace . . . but your competitors will be of higher caliber! Here's a look at both quantity and quality. (p. 355)

CE is edited for the engineer concerned with chemical operations, whatever his function . . . administration, production and plant operations, design, research and development, sales. More engineers subscribe to CE than to any other magazine in the field. Print order of this issue:

43,000

Chemical E

JUNE 1957

Developments in Chemical Engineering

Practice of Chemical Engineering

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46
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54
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64
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Engineering

Vol. 64, No. 6

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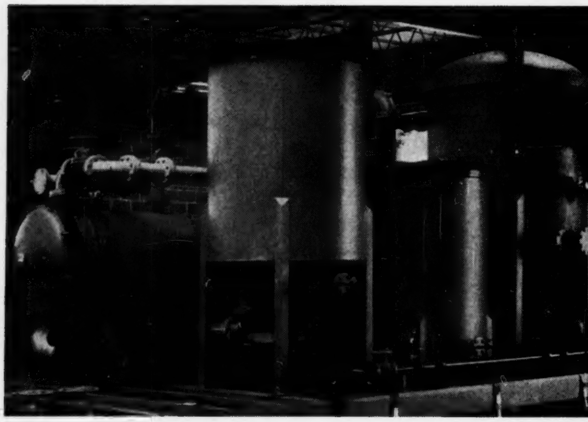
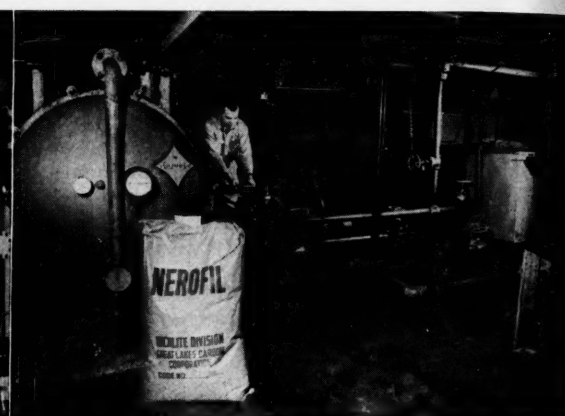
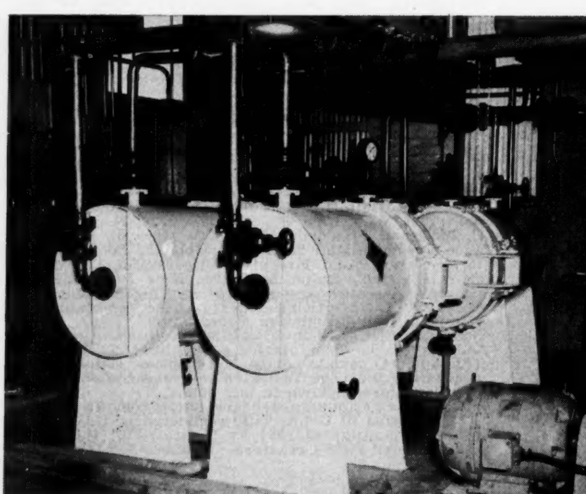
Industrial chemistry?...

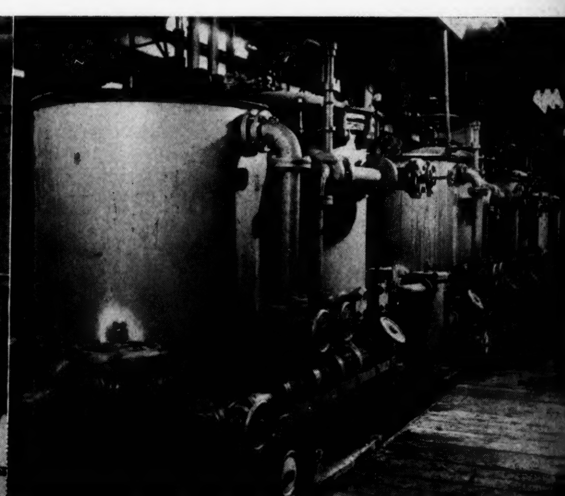




PETROLEUM . . . Certain oil fields that have yielded all oil under normal pressure from underground pools still retain a good deal of usable oil locked in porous rock and shale. By forcing water thru the rock, the oil is driven out and then pumped to the surface. The water used in this process is taken from any available source but must be free of all solids as these would soon fill the pores in the rock formations and the well would cease to produce until the pores were reopened with an acid form of cleaning. This vertical leaf pressure filter was built for heavy-duty rapid purification of water, designed with quick positive cleaning features.

TEXTILES . . . Mercerizing is a process which consists of running cotton thread through a bath consisting of a Caustic Soda solution. This is performed prior to dying and is responsible for its superior luster and strength. These Industrial Horizontal type Filters continually remove all foreign or suspended particles from the Caustic Soda down to 2 microns . . . thus producing a cleaner, finer cotton thread. Cleaning is especially easy. When the filter is open, a truck can be placed under the leaves and a shaking device shakes the cake from the leaves directly into the truck.





FOOD . . . This battery of 4 Tubular Filters is used for final clarification of sugar liquor. Operated two at a time they process 27,000 lbs. in 15 minutes and from 5 to 11 batches can be treated before cleaning. Tubular Filters were recommended by Industrial for economy and convenience in processing various sizes of batches. Each contains 7 perforated tubes lined with filter paper. Cleaning is especially convenient . . . the filter papers are simply taken out and replaced.

METALS . . . The handling of a hot complex sulfate solution in a large plating installation points up two important Industrial features. These filters are particularly convenient to use in parallel for large jobs . . . each filter can be dropped out for cleaning without interfering with the rest of the units. These filters are rubber-lined for corrosion resistance. Remember . . . properly engineered solution and water filtration equipment is the key to quality production.

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Chemical Engineering

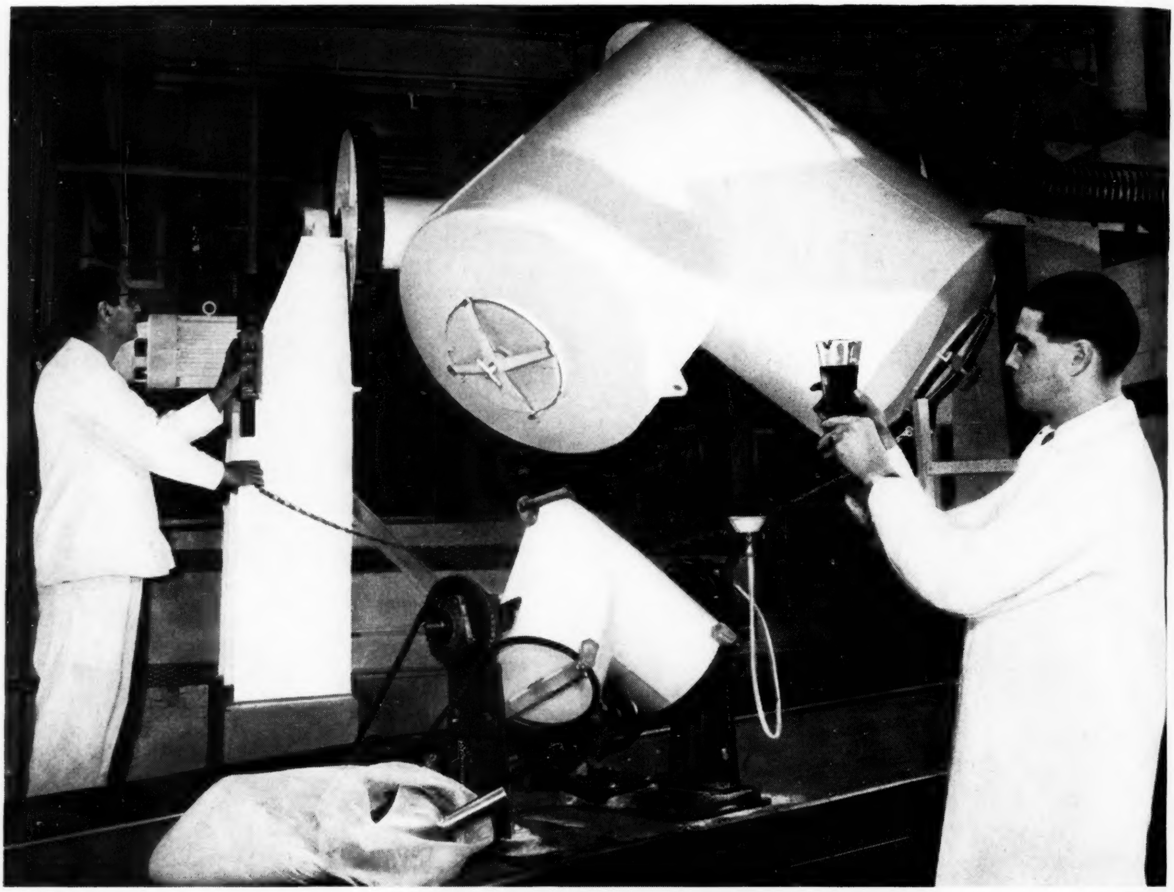
Developments

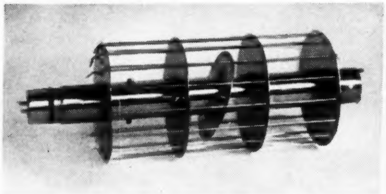
JUNE 1957

Department Index

Now! For the first time

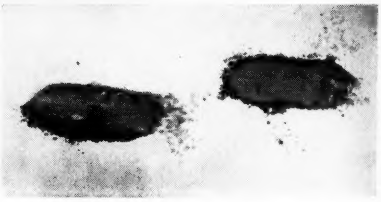
intimately blend any liquid, regardless of viscosity, into dry solids – in one fast step – even up to 40% liquid volume by weight





VERSATILE. This wire cage assembly gives you three blenders in one. With it you can blend liquids into solids, or obtain dry intensive mixing action. Remove it and get gentle blending.

TYPICAL EXAMPLE. Bar breaks down agglomerates in material at left and prevents new agglomeration as liquid is added. Note uniform consistency in finished blend at right.



ABSOLUTE UNIFORMITY. Laboratory smear test reveals streaks where standard blending methods are used (left). With P-K's exclusive design, complete blending is assured (right).

These results can be proved in your own lab with a P-K Laboratory Model Liquid-Solids* Blender. 8 or 16 qt. capacity available from stock for instant delivery.

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*Patents pending

DEVELOPMENTS . . .

JUNE 1957

Chementator

C. H. CHILTON

√ **G. D. Searle & Co. plans to bring out a new ethical drug which shows promise in fertility control. Initial use will be for menstrual disorders.**

√ **Diamond Alkali has modified its diaphragm-type chlorine cell to reach a rating of 30,000 amp., now offers it for licensing.**

√ **A new water-cooled camera of German design can take pictures inside furnaces at temperatures of 1,800 C. Camera covers an angle of view of 70 deg.**

√ **General Electric's motor rerating program, just completed, may lead within five years to further motor improvement through new applications of synthetic polymers in motor design and construction.**

Inert gas cools hot uranium pellets

Latest idea in nuclear power reactors—and one with lots of promise—uses a helium-neon coolant passing through a bed of sintered "homogeneous" pellets composed of enriched uranium carbide fuel and graphite moderator.

Such a reactor, rated at 15,000 kw. of electrical output, will be jointly designed and built for a group of nine West German utility companies by Brown, Boveri & Co. (Mannheim) and Krupp (Essen). It represents the first firm order for a German-designed reactor.

The new German reactor will operate at 1,600-1,800 F., with steam generation at 975 F. These temperatures, which are in the range of those used by modern coal-fired power plants, give substance to the Germans' anticipation of competitive nuclear power costs.

In contrast, the nuclear reactor designs getting the most attention here operate at much lower temperatures. The 60,000-kw. pressurized-water reactor at Shippingport, for example, will generate steam at about 485 F. Argonne National Laboratory's 5,000-kw. boiling-water reactor, which began generating power early this year, also operates at this same temperature level.

The German combination of ceramic fuel pellets and inert-gas cooling seems eminently suited for the proposed high-temperature conditions.

Pay adjustments for older engineers?

What help can experienced engineers expect from organized collective-bargaining units in winning salary adjustments in line with the increasing starting salaries paid to new graduates?

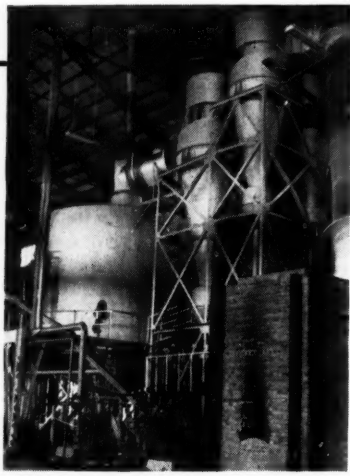
Not much, judging by these three latest developments on "detelescoping" negotiations:

• At Standard Oil (Ind.), Whiting, the Research & Engineering Professional Em-

(Continued on page 142)

Fe H_2SO_4 Cu

"Everything From a



One of two 20 ft. dia. FluoSolids Reactors roasting 235 metric tons per day of crushed pyrrhotite ore at Dowa's Okayama Plant.

Fluidization—

key to maximum utilization in Japan

Processing copper bearing pyrrhotite ore, the Dowa Mining Company at the Okayama, Japan plant is producing . . . and all from the same raw material . . . sintered iron ore for blast furnace use, cement copper and sulphuric acid.

Of major importance in this unique installation is the Dorrco FluoSolids System, consisting of two 20 ft. dia. Reactors plus auxiliary equipment. Utilizing the proven principles of fluidization, the crushed raw ore is roasted under controlled conditions in the System providing SO_2 gas for contact acid manufacture. Roaster calcine is acid leached for copper recovery and leach residue is sintered as blast furnace feed.

The Dorr-Oliver research, design and engineering staffs and our Associates in Japan, Sanki Engineering Co. Ltd., of Tokyo, have collaborated with Dowa Engineers before. At Dowa's hydro-metallurgical plant in Kosaka, Japan, the Dorrco FluoSolids System is a prime factor in the world's first successful roasting of copper and zinc with electro winning of both metals. In the Okayama installation as at Kosaka, manufacture of the FluoSolids Reactors and a number of components in Japan with auxiliary equipment furnished from the U. S. proved to be most advantageous to Dowa.

This is but another example of how the flexibility of the Dorr-Oliver World-wide engineering organization can work to the advantage of a client. It can work for you . . . For detailed information on D-O equipment and services involving the separation of finely divided solids in suspension or fluid techniques, drop a line to Dorr-Oliver Inc., Stamford, Connecticut.

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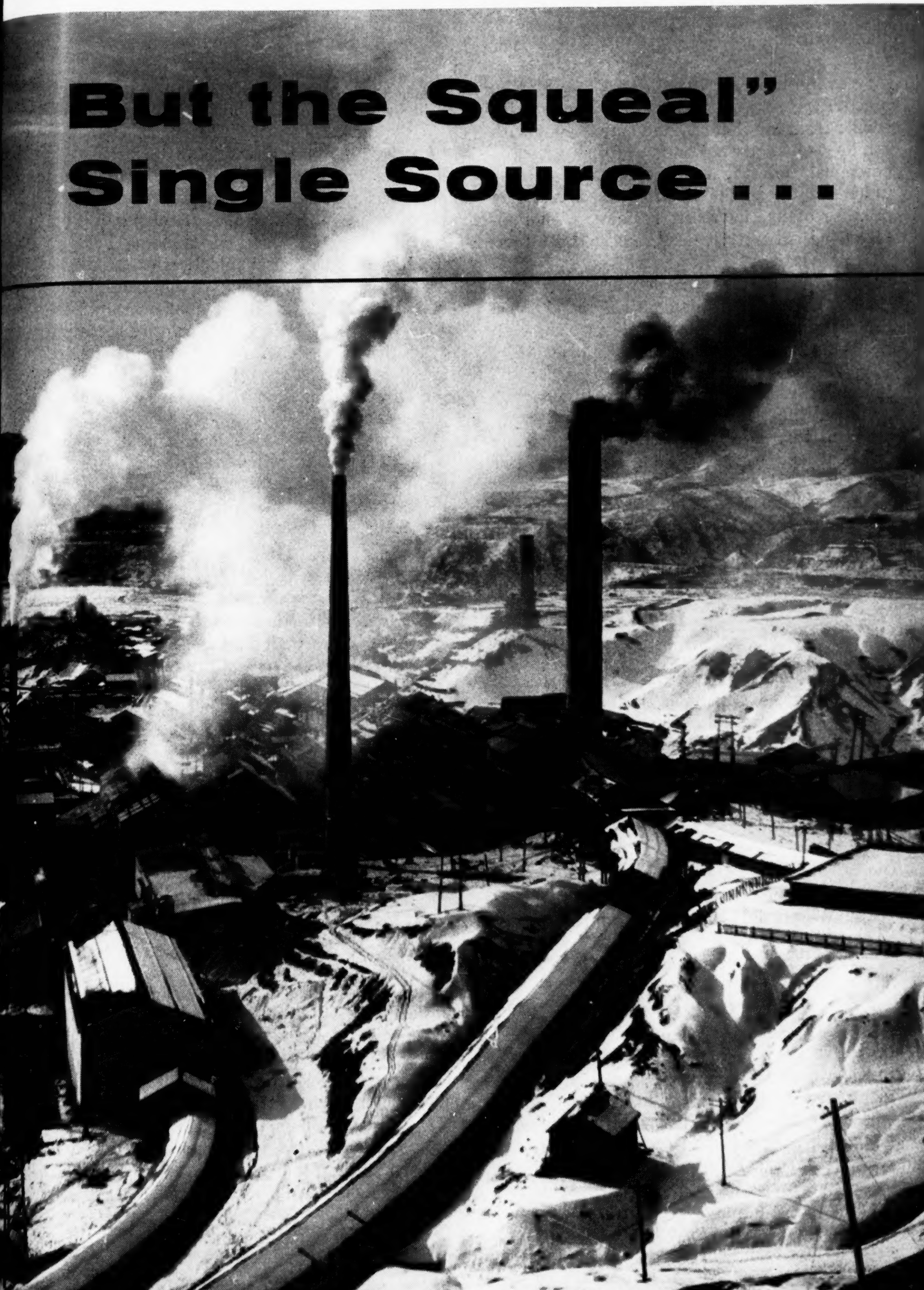
Dowa Mining's Kosaka hydro-metallurgical plant where Dorrco FluoSolids System roasts 83 metric tons of complex copper-zinc concentrates per day.

But the Squeal" Single Source . . .



ployees Assn. finally voted, late in April, to accept a general 4% salary increase, after earlier insisting that the company include with it a 6½% inequity adjustment for experienced personnel. For the time being, at least, the union must content itself with a company promise of special merit reviews, with individual adjustments where management feels they're needed.

• At Shell Development, Emeryville, Calif., the Assn. of Industrial Scientists has brought up again, in informal discussions with the company, a proposal to adjust salaries by ½% for each year of experience after the fourth year. This would be accompanied by an across-the-board raise of 5¾%. Shell management turned down a similar detelescoping proposal last year, doesn't like it any better now.

• At Boeing Airplane Co., the Seattle Professional Engineering Employees' Assn. still hopes to get management acceptance of the principle of detelescoping. The union argues that starting salaries at Boeing increased 26% in the past two years (from $363/mo. in 1954 to $403 in 1955 and $459 last year).

On the other side of the picture are such management arguments as these:

• Salary administration must remain the sole prerogative of management. Blanket detelescoping adjustments would drastically upset well-established salary curves.

• Across-the-board percentage increases benefit the 20-yr. man more than the beginner, anyway.

• The income pattern of our entire society has undergone telescoping in recent years. Why should the engineering profession be treated as a special case?

Engineers' unions may find these arguments tough to refute.

Atomic radiation atomizes coal

Newest use for nuclear radiation is as a tool for very fine grinding. Gamma rays from nuclear reactor wastes can shatter 200-mesh coal particles into particles of 1 micron or less.

Work along these lines is going on quietly in the research laboratory of Denver & Rio Grande Western Railroad. Objective: To cut fuel costs in locomotive operations by incorporating low-cost coal into diesel oil. Tests in a 5-hp. diesel engine have demonstrated the feasibility of adding as much as 5% of the fine-particle-size coal to diesel fuel. Next step: Full-scale tests on locomotives.

To date, several pounds of coal has been irradiated in different ways for the railroad by Brookhaven National Laboratory. Disclosure of details on irradiation procedures and on the methods used by Rio Grande for dispersing the coal dust in the diesel oil is being held up pending filing of patent applications.

Railroads are probably the most price-conscious of all petroleum consumers. "Last year," says Ray McBrian, director of research, "the Rio Grande burned some 40 million gal. of diesel oil. An average price savings of just 1¢/gal. would mean an annual savings of $400,000 to our line alone."

Another approach some roads are trying is the blending of residual fuels with distillates to get a two-fold saving: The residual in the blend lowers the over-all cost per gal. and also raises the Btu. content.

Dual cycle for liquid oxygen, nitrogen

Air Reduction is about to begin $9-million worth of construction at Acton, Mass., the fifth in a series of large air liquefaction plants put on stream in the past five years. Oxygen-nitrogen-argon plants now in operation at Butler, Pa., and Riverton, N. J., will soon be joined by plants now being built at Chicago and at Bassett, Calif.

Although the company hasn't identified the process to be used at its three newest plants, it's a good bet that they'll adopt the dual cycle successfully introduced at Butler and used also at Riverton.

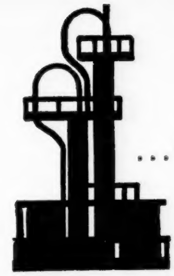
In this process, there are two distinct and separate cycles. The process air cycle, in which air is cooled, liquefied and fractionated into high-purity liquid products, operates at a pressure of about 80 psig. Such a cycle requires more refrigeration than can be obtained by expansion from this low pressure. Additional cooling is supplied by a closed nitrogen refrigeration cycle operating at 2,500 psi. Here's how this cycle fits into the flowsheet:

Warm recycle nitrogen is boosted from 45 psi. to 2,500 psi. in a four-stage compressor. It is then cooled from 90 F. to —4 F. by heat exchange with colder cycle nitrogen that is at a lower pressure. The high-pressure nitrogen is next split into two streams. One stream goes through an expander, where its pressure

(Continued on page 144)

LARGE CRYSTAL

for radiator cleaners, wood bleaches



...OR FINE CRYSTAL

for process use

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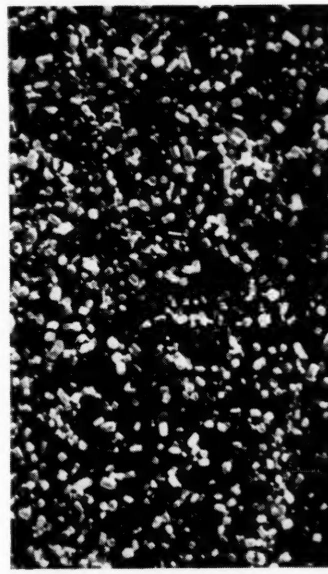

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is let down to 53 psi. and its temperature drops to —273 F. This stream then returns to compression via two heat exchangers—a "cold" exchanger, where it refrigerates the second nitrogen stream, and the "warm" exchanger referred to previously.

The second high-pressure nitrogen stream, now at —245 F., is further refrigerated by expansion through a valve. It gives up more heat (and is liquefied) by furnishing boilup heat to the impure liquid air in the process nitrogen column. From here on, the cycle nitrogen serves the main process as a refrigerant, picking up heat from various process streams, until it finally reaches room temperature and finds its way back to the recycle compressor.

Main elements of the low-pressure process air cycle are the compression section, a reversing-exchanger section and the separation-rectification section. The latter consists of nitrogen, oxygen and argon columns.

Big idea in uranium: Solvent leaching

Atomic Energy Commission is currently evaluating three schemes for direct solvent leaching of raw uranium ores, any one of which—if proved successful—could obsolete present uranium extraction technology.

All three processes, developed under AEC contracts, involve much the same approach: Percolation of a mineral acid-solvent-diluent mixture through the ore on a perforated or porous moving belt. Yield is about 85% of uranium in the ore.

Here's how each process works:

• National Lead's process, in pilot plant at Winchester, Mass., uses tributyl phosphate and 70% nitric acid, gets a product running 90% U_3O_8.

• Battelle's process, also in pilot plant, uses acetone and HCl gets a lower-grade concentrate (about 20% U_3O_8).

• Dow's process, through the lab but not yet pilot-planted, uses an octyl phosphoric acid-hexane-sulfuric acid system and gets a 70% U_3O_8 product. Extracted uranium is stripped from the solvent with HCl.

Direct solvent leaching would have the obvious advantage of bypassing all the conventional—and troublesome—processing steps, plus another feature most readily appreciated by operators on the arid Colorado Plateau: It requires no water.

Another new uranium extraction process —this one backed by private capital—electrolyzes a slurry of ore in boiling water.

Theodore Crawford, a Los Alamos chemist, worked out the basic idea at home in his kitchen during the past year. Yucca Mining & Petroleum Co. has backed Crawford to the tune of $35,000 so far, hopes to move the process into commercial operation.

Boiling the slurry during electrolysis is apparently Crawford's key discovery. Otherwise gas would form at the electrodes and interfere with deposition of uranium.

Better grinding features new process

Pillsbury Mills' new flour milling process, hailed by food industry experts as a bona fide technological advance, depends for its success on what Pillsbury calls "turbo" grinding and "turbo" separation.

Grinding and separation equipment are the basic inventions of Henry Lykken of Minneapolis and were developed jointly with Pillsbury. Although Lykken holds many patents in the field of fine grinding, the machines growing out of the past seven years' work, says Lykken, incorporate definite advances.

The new mill, a modification of Lykken's original Hurricane pulverizer, grinds by a combination of impact and fluid energy. An internal, radial-bladed rotor turning clear of the housing at a peripheral speed as high as 30,000 fpm. shatters larger particles by impact. Fine grinding (to less than 1 micron) occurs via interparticle abrasion and attrition within the vortexes between the rotor blades.

Lykken describes the separator as a centripetal classifier, indicating that it has a peripheral inlet and axial outlet. Key to its sharp separation of product cuts is a higher-than-usual dilution with air. This minimizes interparticle interference and gives greater freedom for individual particles to respond to imposed inertial forces.

Pillsbury's enthusiasm for the new process is based on its extreme versatility. In essence, it frees the company from strict dependence on certain types of wheat in order to make certain grades of flour.

While Pillsbury will exploit the new process to advantage in the flour field, the Lykken machines will be available for other industrial size reduction jobs through Lykken's patent-holding company, the Microclomat Co.

For more on DEVELOPMENTS.........146

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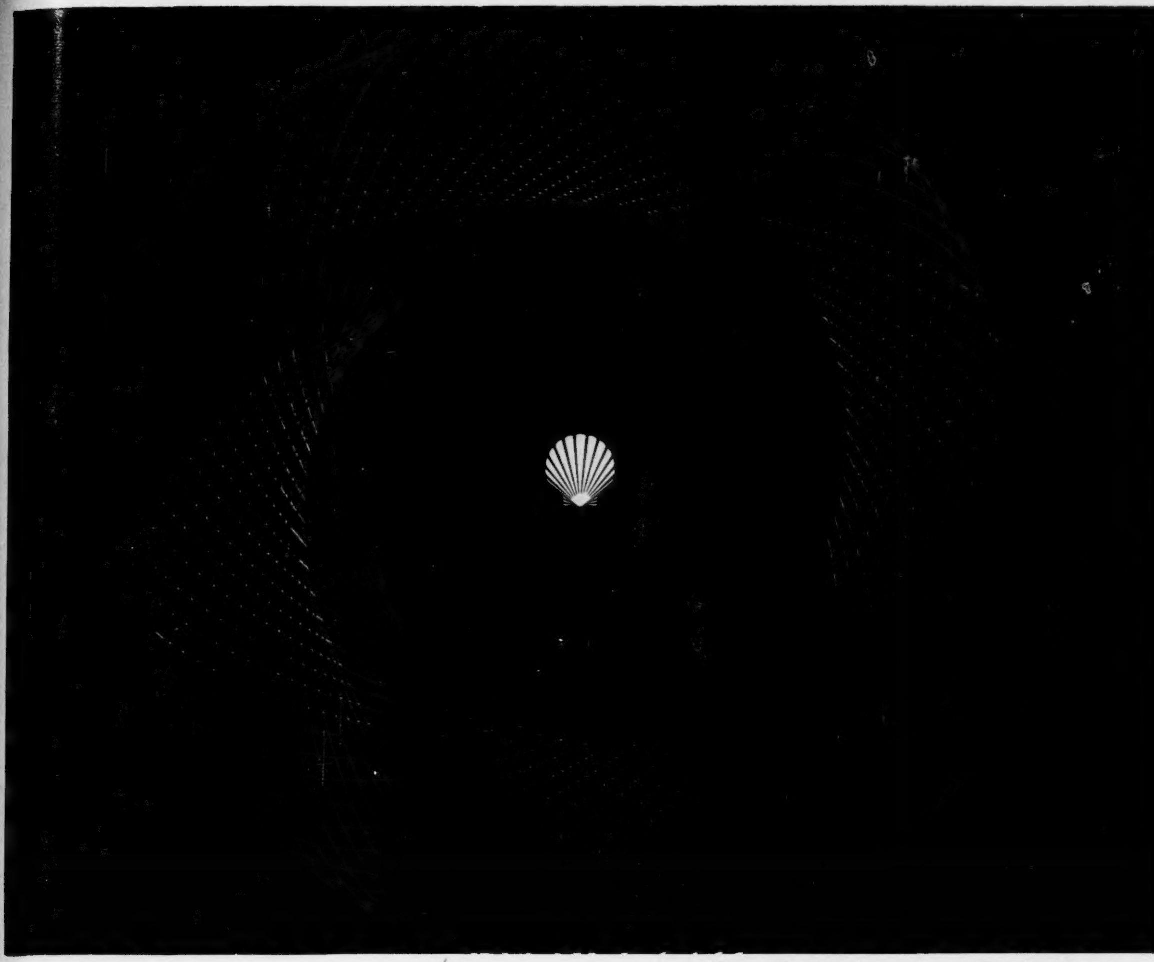

"Integration," an impression by C. Arthur Rosser

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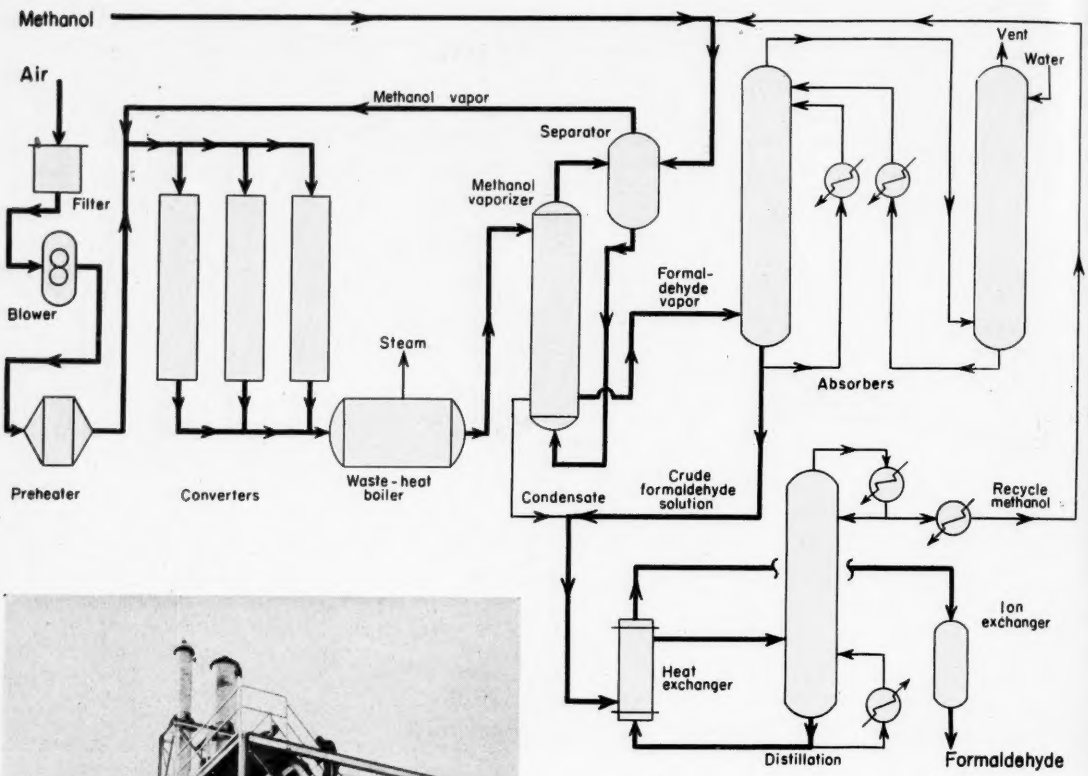
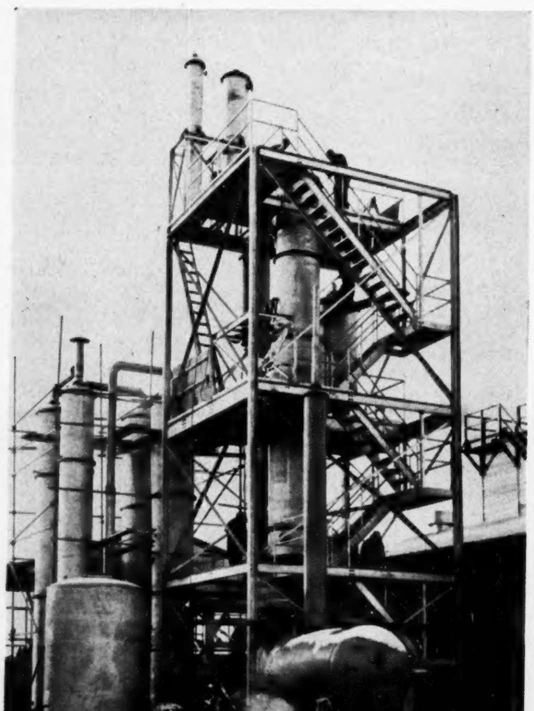
PROCESSES & TECHNOLOGY C. H. CHILTON





ABSORBERS (left) and distilling column (right) form skyline of Borden's new formaldehyde plants.

CONVERTERS—120 of them—oxidize methanol to formaldehyde over a special silver catalyst.

Low Costs Favor New Formaldehyde Process

Two new plants: Put on stream this year on East and West Coasts.
Two processes: Borden combines Fischer process with its own experience.
Two advantages: Higher formaldehyde yields, lower operating costs.

COMPLETING a fast transcontinental one-two punch, Borden Co. has just brought in at Fayetteville, N. C., the second of two new formaldehyde plants using a modified Fischer process. First of the duo went on stream in February in Kent, Wash.

Blend of the German Fischer process with Borden's own formaldehyde know-how has spawned what Borden terms the two most modern and efficient plants in operation today. Principal operating advantages which Borden expects to realize are high product yield and low consumption of utilities. Process converts methanol to formaldehyde via oxidation-dehydrogenation over a proprietary silver-type catalyst.

▶ **Double Entry**—Borden's new plants, numbers five and six in its formaldehyde string, are first in the U. S. to use the Karl Fischer process. The company holds exclusive U. S. sublicense rights to the process, purchased from Karl Fischer Apparate und Rohrleitungsbau in Germany.

Borden states that the process' advantages are based on no single revolutionary development. On the other hand, various individual improvements should add up to a significant total.

"We probably could have worked out these improvements ourselves," explains a company spokesman, "but we decided the wiser course would be to purchase the German knowhow."

▶ **Extra Cost Pays Off**—Borden's anticipated operating economies due to higher yields and lower consumption of utilities will not come scot-free. Although no direct, reliable comparison of construction costs has been made, it's probable that a Fischer-process formaldehyde plant will cost somewhat more than a plant of comparable size employing other dehydrogenation processes currently used in the U. S. This differential might be as much as 10%, according to company engineers.

However, Borden expects to achieve an over-all yield of 93%, compared with usual yields in other dehydrogenation formaldehyde plants around the country of 82-88%.

As to utility requirements, here's what Borden hopes to realize, as compared with published figures (*Chem. Eng.*, Nov. 1954, pp. 109-110) for Reichhold's plant at Seattle:

	Fischer	Reichhold
Steam, lb.	0.5	0.8
Water, cu. ft.	0.5	0.9
Power, kwh.	0.02	0.08

Figures are based on 1 lb. of 37% uninhibited formaldehyde.

▶ **Captive and Merchant**—Borden uses formaldehyde in making phenol, urea and resorcinol resins; it also sells formaldehyde commercially to the resins, plastics and chemical industries.

The company's first formaldehyde plant went into operation at Springfield, Ore., in 1946. The Kent plant now boosts Borden to the top among West Coast formaldehyde producers. Although Kent's present capacity is the same as that at Springfield, the older plant has already reached its practical limit, while output at Kent can be doubled readily.

With the Kent plant running at top level, the Springfield unit will be shut down for a much-needed, long-delayed overhaul.

With two other Eastern plants (Demopolis, Ala., and Bainbridge, N. Y.) in addition to the new Fayetteville plant, Borden can now serve the entire Atlantic Seaboard with overnight tank-truck deliveries. Moreover, the company maintains a bulk-storage formaldehyde depot in the Chicago area for serving customers in the Midwest.

▶ **Fischer Process Operation**—The flowsheet (left, above) shows the basic scheme of the Fischer process as reduced to practice by Borden at Kent and Fayetteville. Here are some of the features which contribute to its operating savings:

- Exothermic heat of reaction is carefully conserved by passing 600-C. gases from the converters first through a waste-heat boiler and then to a second exchanger, where added heat is recovered by vaporizing the methanol supplied to the process. This also saves on cooling water in the absorption step.
- Borden has designed for low pressure drop in order to minimize power consumption of the air blower. This includes the use of two parallel sets of absorption towers.
- Less-than-complete conversion of methanol minimizes losses as water and CO_2, while distillation of raw formaldehyde recovers unconverted methanol for recycling to the process.
- Product goes through an ion exchange unit to bring formic acid content down to less than 0.01%.

▶ **Plant Engineering**—Process equipment and product storage

tanks are made of Type 304 ELC or Type 316 stainless steel. Methanol storage tanks are of steel.

Process air is supplied by a 50-hp. positive-displacement rotary blower.

There are 120 vertical converters, each some 4-6 in. dia.

The two first-stage absorption towers are each 44 in. dia. by 26 ft. high, packed with carbon Raschig rings. The second-stage towers are each 30 in. dia. by 26 ft. high, also packed with carbon rings. The distillation tower is 47 in. dia. by 36 ft. high, containing 40 plates.

Site and supporting facilities were selected with future expansion in mind. Boilers and cooling towers, for example, are much larger than required by the two plants today. And with formaldehyde demand holding strong, such expansion may not be far off.

Firm Will Supply AEC With Lithium-6 Isotope

U. S. Atomic Energy Commission has just taken security wraps off some of the details of its five-year contract with Foote Mineral Co. under which Foote will supply AEC with lithium hydroxide.

Currently, AEC is chiefly interested in one of the two naturally occuring isotopes: lithium-6. Still classified are the quantity of material involved and AEC's end use for lithium.

However, tails (material depleted with respect to lithium-6 isotope) are resold to the company at the original selling price (minus a small credit for rehandling) and can be made available commercially. At the present time, three major lithium producers are supplying "virgin" lithium hydroxide to AEC. Tails are resold only to the original producers in the same proportion in which it was supplied. Chemically, this material is identical to virgin lithium hydroxide.

Under Foote's second certificate of necessity for lithium expansion, the firm's lithium-producing facilities are being amortized over the five-year period of the contract. AEC is committed to withhold sale of unreturned lithium for ten years after the end of the current contract.

Reveals Versatile New Route to Tetraethyl Lead

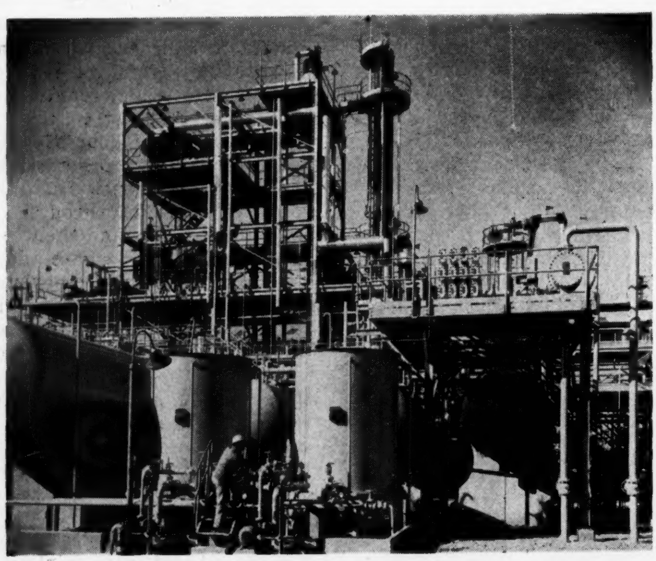
Ethyl Corp.'s continuing search for new and better ways to synthesize organolead compounds (particularly tetraethyl lead) has paid off well with radically new, versatile syntheses for TEL and triethyl aluminum.

However, Ethyl stresses that, as far as TEL is concerned, the new methods are still very much in the lab-bench stage. Present TEL synthesis offers definite economic advantages.

Commercial TEL process involves reacting a sodium-lead alloy with ethyl chloride. By the new method, Ethyl research chemists have been able to synthesize TEL from a wide range of organometallic and common lead compounds.

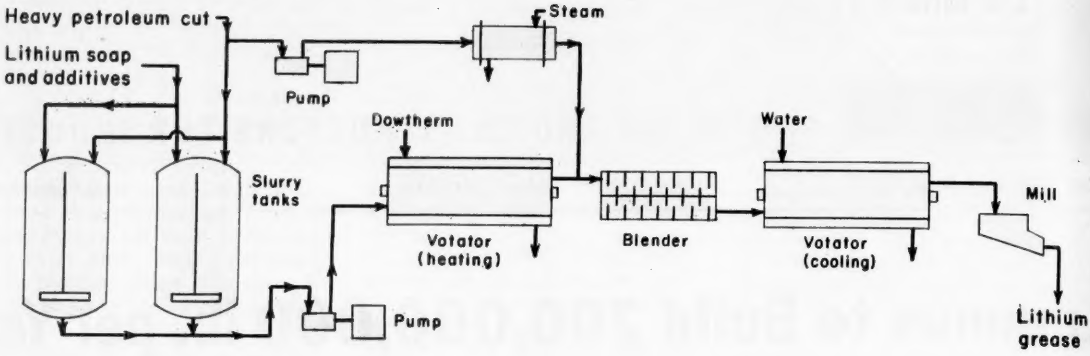
Project Manager S. M. Blitzer, of Ethyl's research and development department, notes that one of the most significant finds is that lead sulfide, oxide and dioxides react with organometallic compounds to form TEL. Researchers also found that reactions take place at mild temperatures and proceed at moderate to rapid rates. And in many cases they achieved high yields of TEL.

New route to triethyl aluminum was uncovered during the same research program, and Ethyl Corp. has just received a patent (U. S. 2,787,626) on the process. It uses aluminum, hydrogen and ethylene as raw materials, involves moderate temperatures and pressures. Triethyl aluminum has stirred interest as an important ingredient in catalysts for high-density polyethylene and other olefinic polymers.



New Plant Turns Out Pellets of Rigid Polyethylene

Here is a section of Phillips Chemical Co.'s new 75-million-lb./yr. polyethylene plant on the Houston, Tex., ship channel. Plant's startup marked first commercial production of Marlex 50 rigid-type polyethylene. Production is scheduled to reach full capacity during the final months of this year.



New Grease Process Ousts Batch Kettles

Pros of continuous operation outweigh cons, concludes big-volume producer of lithium grease, but there's no bandwagon rolling yet.

Continuous manufacture of lithium grease may finally be getting the commercial green light from the traditionally batch-kettled grease industry.

This summer Surpass Petrochemicals will complete its first year's operation of a new $375,000 continuous lithium grease plant at Toronto, Ont. A virtual giant as grease-making operations go, the plant can turn out 25 million lb./yr. (3,000 lb./hr.) of the lubricant—more than twice current Canadian domestic demand. And, a Surpass spokesman reports, the plant can and will be adapted for other greases.

Engineered by the Girdler Co.—a vigorous continuous-grease-process advocate—the Surpass operation tandems on two of Girdler's Votator heat-transfer units. The first heats a slurry of lithium soap in oil, while the second chills the blended grease to a gel. These two key grease-making steps are conventionally handled by open batch kettles.

▶**Split Opinion**—Lithium grease, a multipurpose lubricant that's snaring markets once served by a myriad of specialty formulations, has long looked like a natural for continuous processing.

Yet the Surpass plant is only the second to date in the U. S. and Canada to rate the completely continuous label. First was Shell Oil at Martinez, Calif., on stream in 1950. Time lag between the two, says an industry observer, is a good indication of the split opinion over continuous processing's merits.

▶**Pro Continuous**—Surpass now offers these convincing reasons for joining the continuous-processing camp:

- Process permits good control of operating variables and keeps materials at high temperatures for only a short time, thus yielding highly uniform products.
- Equipment requires some 75% less floor space than a batch plant of equal capacity, thanks to its high rate of throughput and compactness.
- Operations are completely enclosed, thus beating fire hazard, loss of volatile materials, contamination and aeration of final formulation.
- Process requires 30% less power, thanks to ease of milling product, and less heat, since only half the oil need be heated and radiation heat losses of open kettles are eliminated.

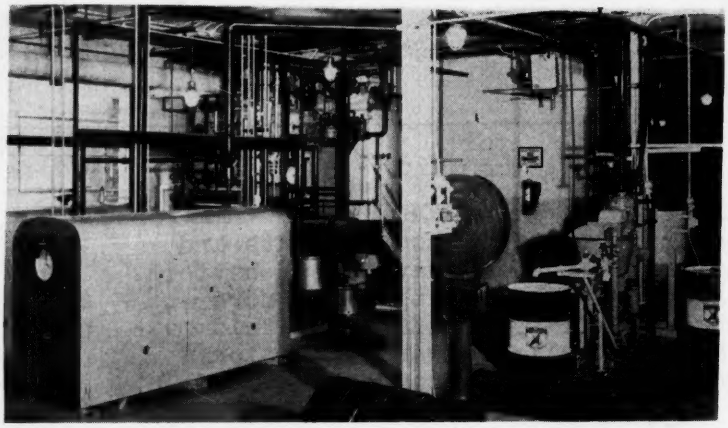
Another advantage specific to Surpass: The firm is a subsidiary of Montgary Explorations, which is currently developing an 8-million-ton lithium ore body at Bernic Lake, Man. By next January Montgary will be supplying a full range of lithium soaps to Surpass.

▶**On the Other Hand**—While granting these handsome features, other grease manufacturers stress what they consider to be continuous operation's discouraging disadvantages:

- It loses the batch plant's ability to produce a wide range of products. Despite lithium grease's broad versatility, grease makers market it in a variety of grades and produce other greases as well in the same facility.
- It must be run at high production volume to be economical. Yet markets for any particular formulation aren't big enough to warrant hefty production rates.

Continuous operation thus creates storage and inventory problems and, so goes the indictment, the unit must be shut down intermittently to secure necessary plant flexibility. Moreover, with the soap-making step still a batch procedure, the continuous grease route is not entirely continuous anyway. It makes more sense, some producers feel, to combine soap manufacture, soap-oil slurrying and heating in a single batch kettle.

▶**Compromise**—At Shell these pros and cons balanced each other. While the 1950 Martinez



GREASE is finished in water-cooled Votator (left) and mill (right).

plant uses the Girdler-Votator scheme, a 1952 expansion at Shell's New Orleans facility elected to stay batch.

And other grease makers, weighing one set of persuasive arguments against the other, are coming up with a neat compromise that seems to make the best of both—semicontinuous processing. Manufacture of soap, its dispersion through oil and subsequent heating and blending remain batch. But the chilling operation becomes the job of Votator-type continuous equipment, followed by continuous milling.

▶**How Continuous Process Works** — A heavy petroleum fraction is charged to one of two 300-gal., agitated, steel slurry tanks. Only half the total oil required is introduced at this point.

A single-stage steam ejector pulls a 4-in.-Hg vacuum on the slurry tank to deaerate the oil. Lithium stearate and additives (e.g., oxidation inhibitors, coloring agents) feed from hoppers into the evacuated slurry tank. After proper mixing, this charge is ready to go on the line when the charge in the other tank is used up.

▶**Heating Votator** — Slurry feeds through the heating Votator, where its temperature is raised from 85 F. to 400 F. during a residence time of three minutes.

This unit consists of a Dowtherm-jacketed cylinder fitted with a heavy agitator shaft rotating at 300 rpm. via a 10-hp. motor. Longitudinal blades mounted on the shaft scrape slurry from inner cylinder wall to insure high heat-transfer rate and provide additional soap-oil mixing.

▶**Blending and Cooling**—Remaining half of oil, steam-heated to 190 F. in a shell-and-tube exchanger, is added to hot Votator discharge in a 10-gal., agitated, steel blender. Blending takes place at 300 F., with the agitator rotating slowly (60 rpm.) to avoid high shear. Here formation of the grease gel structure begins.

Blended material then flows through the cooling Votator to drop its temperature, during a 1½-min. pass, to 140 F. This forms a highly stable soap matrix and completes the gel formation. Unit is similar to the heating Votator except it is cooled with 65-F. water.

Chilled grease is milled, deaerated and barreled for shipment. Only one man is required for the entire operation.

New Rotproofing Process Will Use Acrylonitrile

A new rotproofing process for textiles has joined cyanoethylation, acrylonitrile-based fabric treatment process pilot-planted earlier by Monsanto and American Cyanamid (*Chem. Eng.*, Oct. 1954, p. 112).

Though neither process has yet received wide commercial acceptance, they both show a lot of potential and may eventually compete for the same markets.

New process, developed and offered for licensing by Tee-Pak, Inc., Chicago manufacturer of sausage casings and food-packaging materials, improves mildew and rot resistance of fibers and increases their breaking strength by laying down a protective coating of chemically bonded acrylonitrile. Treatment has been used on such fibers as cotton, rayon, burlap, canvas, rope, jute and paper.

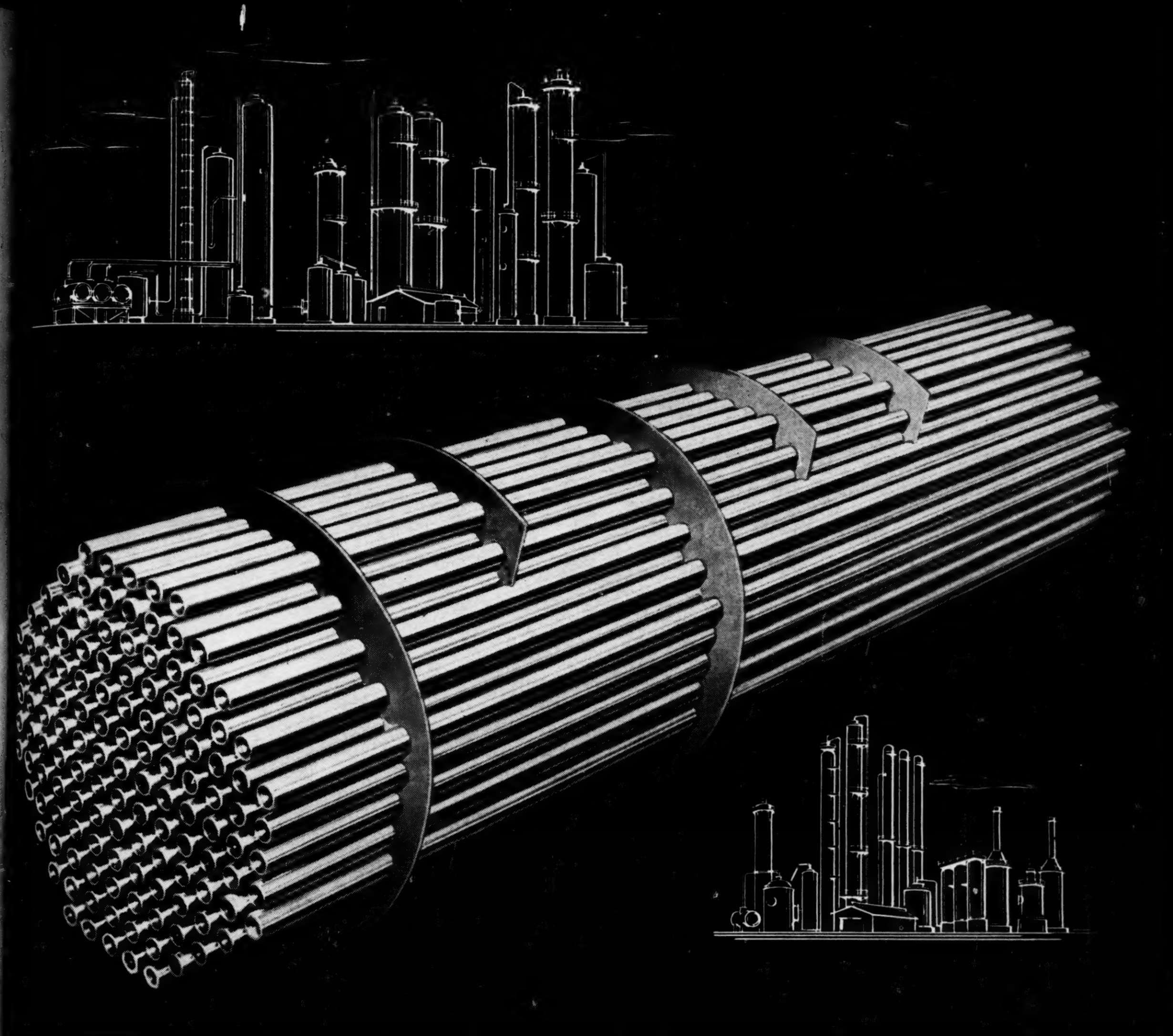
▶**Vs. Cyanoethylation** — Tee-Pak's process is something like cyanoethylation in that it does about the same job and uses, among other chemicals, acrylonitrile. But process chemistry and details are a lot different.

In cyanoethylation, acrylonitrile reacts with the hydrogen of fiber's hydroxyl groups, forming a cyanoethyl ether group. This is done by a continuous process involving treatment with caustic, acrylonitrile and acetic acid, and then washing and drying.

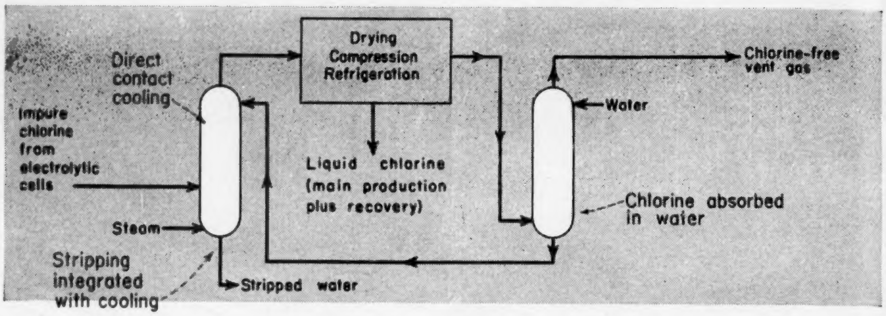
Tee-Pak uses ferric ion as a catalyst, involves reaction of acrylonitrile with cellulose carboxyl groups and polymerization of the acryonitrile. Ferrous ammonium sulfate supplies ferrous ions, which replace the hydrogen of the carboxyl groups. After acrylonitrile and water are added, hydrogen peroxide is introduced to convert ferrous ions to ferric, and acrylonitrile polymerizes preferentially at the carboxyl site.

▶**No More Equipment** — Tee-Pak won't come right out and pick a fight with cyanoethylation, but here's what it feels its process has to offer: It's simple; you don't need extra equipment, can use standard wet-finishing machine. (Cyanoethylation calls for an added recovery system to be economical.) Too, Tee-Pak process is easy to control and looks as though it will be low in cost.

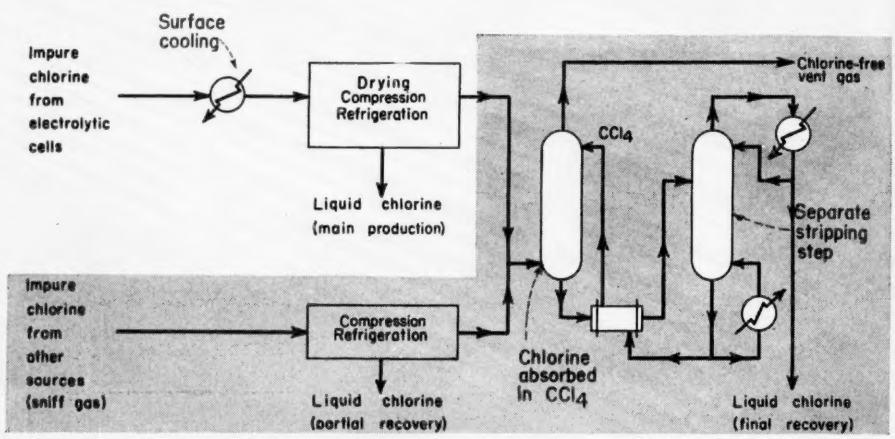
However, don't count out cyanoethylation. Contrary to some reports, Cyanamid does not feel that cost figures reported last year for the process were too discouraging, and the firm is still toying with cost-reducing ideas.



Hooker integrates recovery with main production



Diamond's process can be added by existing Cl_2 producer or user



For Chlorine Recovery, Take Your Choice

Necessity for air pollution control has mothered another invention—this time in the chlorine industry.

The culprit: "Sniff gas," or "blow gas," a residual mixture of chlorine and noncondensables lost to the atmosphere during chlorine liquefaction and/or transfer, storage and salvage. Blow gas from liquefaction is 30-40% Cl_2 by wt.

The cure: Either of two efficient, economical chlorine recovery schemes developed independently by Hooker Electrochemical and Diamond Alkali. Each technique is now available for licensing; each possesses advantages that are more complementary than competitive.

▶ **Units Up and Coming**—Both firms are showing off their processes in their own plants: Hooker, at Montague, Mich., Tacoma, Wash., and (soon) Vancouver, B. C.; Diamond, at Muscle Shoals, Ala., Edgewood, Md., and Deer Park, Tex.

Hooker already has two active licensees—a large French chlor-alkali producer and an integrated American chlor-alkali maker—and two or three interested negotiators. Diamond is dickering with three potential licensees (including two big users of chlorine who buy the stuff by the bargeful, regret having to return a product heel each trip to the supplier). Associated Ethyl of England will begin using Diamond's recovery process within a month.

▶ **Integral vs. Incremental**—Hooker tightly integrates its recovery system with cell gas liquefaction. Water normally ticketed for direct-contact cooling of hot cell gas in a packed tower is used first to absorb chlorine from sniff gas vented from the liquefaction unit.

Getting double duty from the water this way means that the only extra factor needed is the absorber. Hence, the modest initial capital outlay, for a 170-ton/day chlorine plant, of around $30,000, with little in the way of extra operating costs.

Diamond chose to set up a self-sufficient unit with carbon tetrachloride as absorbent, a unit which can readily treat chlorine-containing gases within an existing chlorine plant or wherever chlorine is handled, whether by producer, merchant or user. Capital investment tab: $140,000 for a 100-ton/day chlorine plant. Operating costs: $19/ton recovered chlorine. (Diamond's package unit includes its own refrigeration plant. Knock off about $60,000 from capital cost if you

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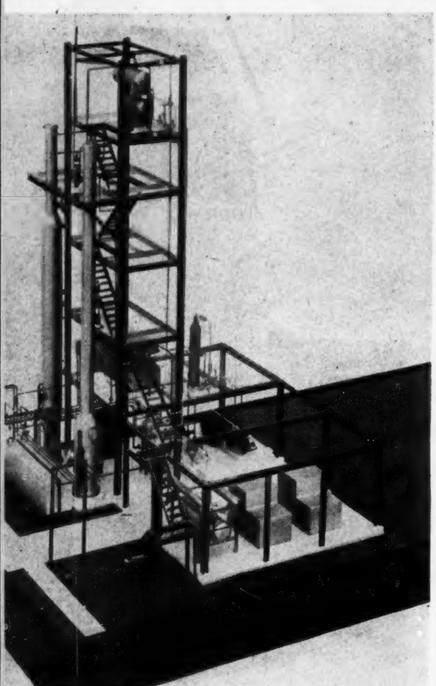


PACKAGE UNIT offered by Diamond absorbs Cl_2 in carbon tet.

choose to rely on main plant facilities.)

Thus, Hooker's process is cheaper, more expedient, if direct cooling is in the picture and integration is possible. In return for the extra cost, Diamond offers greater flexibility and wider adaptability. Hooker's process is tailored to liquefaction vent gas; Diamond's is a "chlorine recovery" process.*

▶ **Recovery Pays Its Way**—Sniff gas has been put to profitable use in the past via manufacture of bleach, chlorobenzene, or HCl. Usually, though, it has been more economical to vent the chlorine-containing gases to the atmosphere.

But, as one chlor-alkali chemical engineer candidly puts it, "Increasing emphasis on air pollution abatement means this method of disposal has a short life expectancy."

Looking to the future, Diamond and Hooker have come up with preventive medicine for future pollution headaches that will, as it turns out, do more than break even costwise.

For complete recovery of waste chlorine can bring a tidy return to the manufacturer. Diamond estimates even a chlorine plant with low-level refrigeration will lose 2% of total chlorine produced by the cells; higher-level refrigeration will permit 4% to get away. Another 2% may be lost at other points—chlorine transfer, loading and unloading, etc.

▶ **How They Work**—In Diamond's process, sniff gas, regardless of source, is first compressed to about 100 psig., cooled and a portion of the chlorine component liquefied. Vent gas from this liquefaction then moves to an absorber (a 30-ft. high, 16-in.-O.D. packed tower) where it contacts carbon tetrachloride. Carbon tet enters the absorber at 0 C., exits at 80 C. countercurrent to the incoming gas stream. Chlorine-free gas is vented to the atmosphere. Chlorine-rich carbon tetrachloride goes to a stripper where hot CCl_4 distills out pure Cl_2 product. Stripped solvent returns to the absorber. Carbon tetrachloride losses are about 30 lb./ton recovered chlorine.

Hooker runs hot cell gas against water and steam in a combination cooler-stripper. The water has been saturated with chlorine and carbon dioxide from sniff-gas absorption further on in the process. Stripped water is discarded from the bottom of the cooler-stripper.

Cooled cell gas is dried, compressed and cooled, the liquid chlorine product representing primary production plus recovery. Liquefier vent gas (Hooker's sniff gas) proceeds to a 30-ft., 42-in.-O.D. packed tower for absorption in fresh water.

Clean gas goes out the top, chlorine-rich water goes out the bottom en route to the stripper-cooler.

▶ **Carbon Tet vs. Water**—Some points of comparison are worth noting. Diamond recycles 8-10 times more CCl_4 than is normally needed for absorption duty. This makes for easy operation and surge capacity. And CCl_4's absorptive capacity for chlorine is 10-12 times that of water.

Water throughputs in Hooker's cooler-stripper and absorber are interdependent and must, in addition, be regulated to prevent buildup of noncondensables in the system. (CO_2 is less soluble in CCl_4 than in water.)

In addition, wet chlorine is a far different beast, corrosion-wise, than is dry chlorine. For example, Hooker's absorber is rubber-lined, Diamond's is all steel (except for Monel cladding at the bottom).

On the other side: While Hooker's system is now tied to chlorine recovery from liquefier vent gases only, there's always the probability that it can handle any chlorine-containing gas by bringing it up to the right pressure and putting it through the absorber.

Nuclear Reactor Planned For Co-60, Steam, Profit

By taking pioneer strides in an infant industry, Isotope Products, Inc., Buffalo, N. Y., expects to turn a private atomic project into a solid, profit-making venture.

Firm in its conviction that radiation processing will soon become a big thing in chemical and allied industries, IP has announced that construction will begin this summer on a boiling-water-type nuclear reactor (*Chem. Eng.*, Apr. 1957, p. 154) designed to optimize cobalt-60 and steam production. On-stream date is 1958.

IP has not specified reactor's location but says it will probably be located near a pulp and paper mill. Nearly a dozen companies in high-fuel-cost areas are already negotiating with IP for steam sale and site location.

Reactor will produce about 1 million curies/yr. of cobalt-60 and 50,000 lb./hr. of steam.

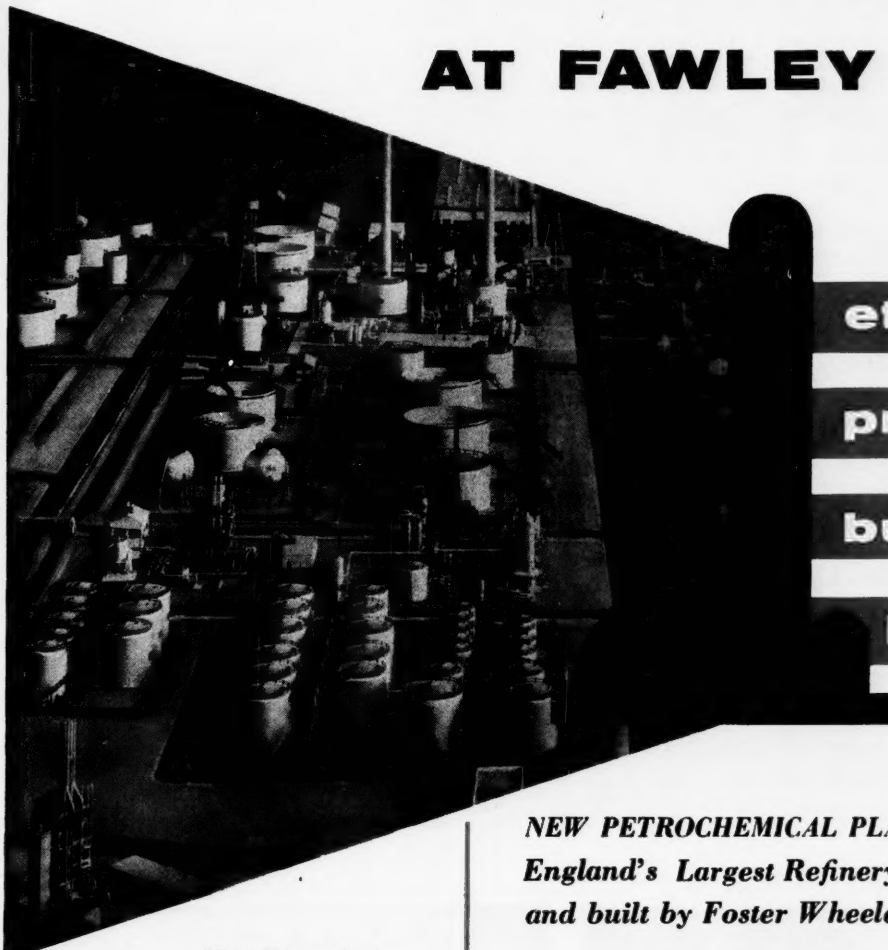
▶ **Co-60 Is Best by Test**—Before making its decision, IP made a careful study of competitive radiation sources and finally decided on cobalt-60 because radiation quality is ideal for process irradiation in bulk form.

Cobalt-60 emits hard gamma rays of 1.1 and 1.3-mev. energy which give good penetration in bulk handling. Moreover, there is no low-energy component to

* Diamond's patent hints at broad usefulness for the recovery of chlorine from gases originating in: electrolysis of magnesium chloride; chlorination of organics; Deacon oxidation of hydrochloric acid to chlorine and water.

petrochemicals

AT FAWLEY



ethylene

propylene

butadiene

butylene

The photograph above shows a scale model of part of the huge Fawley Refinery of Esso Petroleum Company Limited. Foster Wheeler was the prime contractor for this complete "grass roots" refinery. It now has twenty-one process units and more are projected.

Foster Wheeler designs and builds petroleum, chemical and petrochemical processing plants anywhere in the world.

NEW PETROCHEMICAL PLANT for England's Largest Refinery, will be designed and built by Foster Wheeler

SYNTHETIC rubber and plastic hydrocarbon raw materials (ethylene, propylene, butylene and butadiene) will be produced from 250,000 tons per year of petroleum intermediates in a major process installation at the Fawley, England, refinery of Esso Petroleum Company Limited. Foster Wheeler, who built the new Fawley petroleum refinery, the largest in England, will also provide mechanical design and construction for this petrochemical project. Esso Research and Engineering Company supplied basic process design data.

These basic hydrocarbon products represent a new and very substantial source of raw material for the British synthetic rubber and plastic industries.

Foster Wheeler Corporation, 165 Broadway, New York 6, N. Y.

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give higher dose rates near the surface. In contrast, radiation from electron accelerators is best for thin films but causes induced-radiation problems when emission energy is increased to get deeper penetration. And in food processing, especially, this is highly undesirable.

Another plus: Radioactive cobalt offers virtually maintenance-free performance. Once a year the source would be shut down to restore the cobalt unit to full strength (decay loss: about 12%/yr.).

Finally, cobalt-60 is a low-cost radiation source. Compared with cesium-137, for example, cobalt-60 is able to give the same radiation energy at one-tenth the cost. According to IP's President D. C. Brunton, IP expects to make the cobalt for sale at $2/curie.

Pushes Plan for Alcohol Layer to Curb Water Loss

After last year's encouraging tests near Oklahoma City, U. S. Bureau of Reclamation is pushing ahead with its program of study to apply and maintain a layer of cetyl alcohol on water surface to cut evaporation losses.

Bureau is starting experiments this spring at its 97-acre Rattlesnake Reservoir, 12 miles west of Loveland, Colo. Studies are preliminary to applying the method on a large scale to Lake Hefner, part of the water supply system for Oklahoma City. Tests will help evaluate methods of spreading the alcohol.

Cetyl alcohol (normal $C_{16}H_{33}$-OH) has already chalked up impressive test records battling evaporation losses in Australia. It was chosen because it spreads readily on water and forms a continuous monomolecular film. Film allows oxygen and other gases to enter the water while providing a barrier against evaporation. Bureau of Reclamation tests show that cetyl alcohol cuts water loss from pans by as much as 45-64%.

Bureau officials in Colorado estimate that water amounting to 4 ft. of depth is lost each year by evaporation in the area.

Last year's tests showed that the chemical had little or no effect on taste or odor of the water, fish life or water organisms.

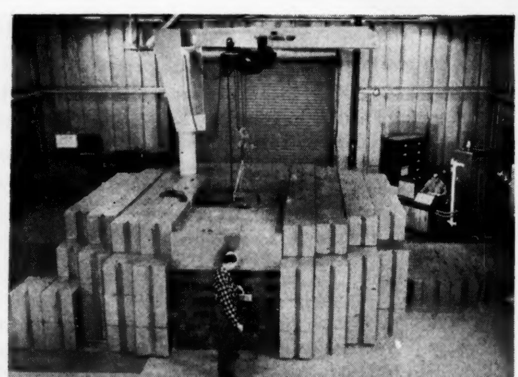
Rubber Firms Push Plans For Chemicals, Fibers

Expansion announcements from three rubber companies involve butadiene, specialty organic chemicals, nylon tire-fabric and, not surprisingly, tires.

B. F. Goodrich Chemical Co. has set early 1958 as on-stream time for a $5-million plant near Henry, Ill., to manufacture specialty organic chemicals, such as antioxidants, for the petroleum, rubber, plastics and other industries.

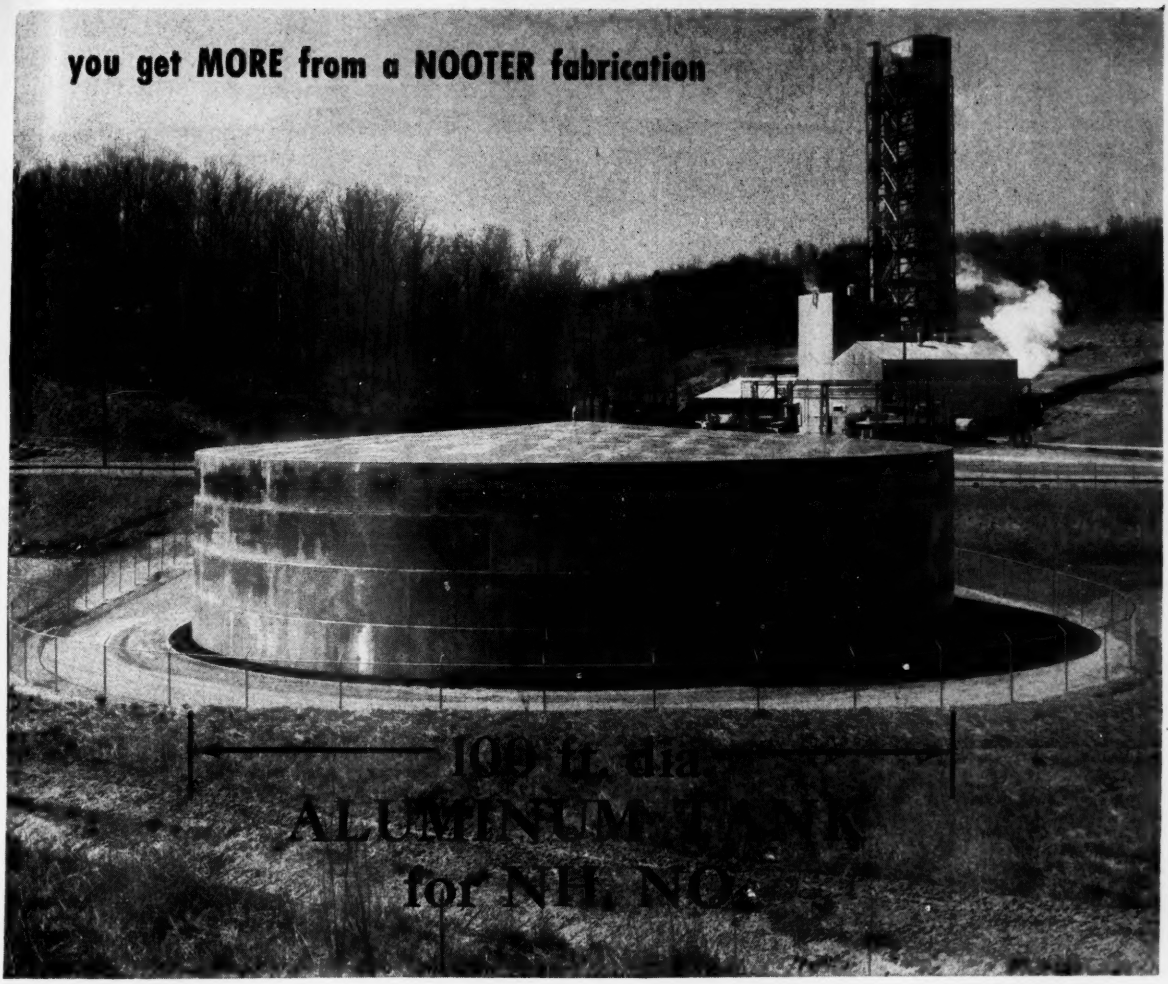
Firestone Tire & Rubber Co. has just completed work on its 40,000-ton/yr. butadiene unit at Orange, Tex., and will soon bring on stream a rubber air-springs plant at Noblesville, Ind., and tire plants in Havana and Manila.

U. S. Rubber is spending $1 million to enlarge nylon tire-fabric facilities at its Scottsville, Va., plant to meet booming demand in the tire industry. The firm also has scheduled a $5-million tire plant in Cuba for completion early next year. Plant will be Cuba's largest, with capacity of 125,000 tires/yr.



New Argonaut Training Reactor Is Low-Cost, Simple, Ultrasafe

Argonaut educational training reactor at Argonne National Laboratory, Lemont, Ill., costing no more than $100,000, can be used to study control-rod response, fission distribution, effects of poisons (neutron absorbers) and bubbles. At left, scientist examines fuel plates in cluster; right, technician checks activity level of a stringer withdrawn from the thermal column.



Here's another big Nooter job, an aluminum tank for storing 83% ammonium nitrate solution. It was built for Mississippi River Chemical Company. This squat, but mighty reservoir has a height of 23 feet, a girth of over 314 feet. Walls and interior structure are aluminum, which was specified for its corrosion resistance to this fertilizer raw material. And Nooter fabricating experience assured flaw-free welds throughout.

But any other material, or any other storage tank design would have been field erected just as perfectly, finally inspected just as carefully and completed on time.

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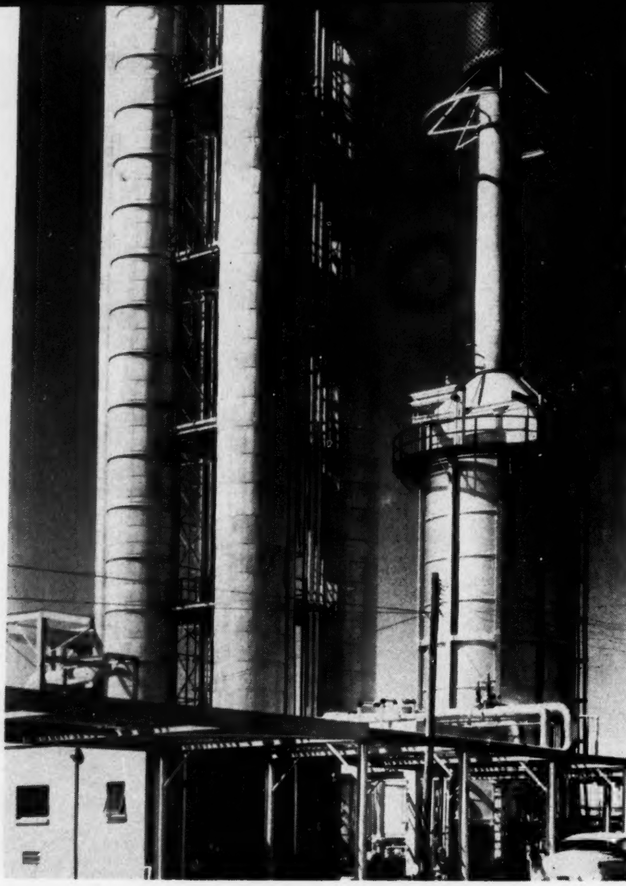
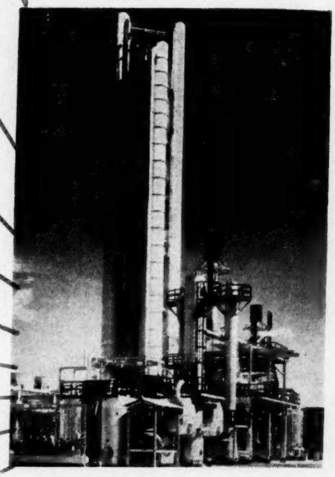




SIX PLATFORMS tie the four skyscraping towers into a structurally stable unit.

Fractionation Taps New Source of Styrene

With only 2.3 C. separating key components, Cosden uses 600 ft. of tower height to coax ethyl benzene from a stream of mixed xylenes.

Courageous process engineering and smart structural design keynote Cosden Petroleum Corp.'s new $3-million, 20-million-lb./yr. styrene-from-gasoline plant at Big Spring, Tex.

Cosden stakes its claim to fame as first and only styrene producer to base its process on direct recovery of ethyl benzene from gasoline. And therein lies the chemical engineering tale.

For Cosden gets its ethyl benzene by fractional distillation of a mixed xylene stream in which the critical cut is based on a temperature difference of only 2.3 C. (b.p. ethyl benzene, 136.2 C.; b.p. para-xylene, 138.5 C.). The xylene stream comes from Cosden's aromatics unit, also at Big Spring.

▶ **In Tres Partibus**—To make this separation requires some 350 plates and 600 ft. of tower height. That's why some experts have considered it impractical to carry out on a commercial scale.

But Badger Mfg. Co., working closely with Cosden on design and construction of the unit, split the 600 ft. of total tower height into three 200-ft. hunks, added a 185-ft.-high tower (used later in the process), tied them together laterally at six platform levels to get a structurally rugged giant quadruped.

Feed enters the first column near its midpoint. Bottoms from this column constitute the stripped xylene mixture. Rectification continues through the next two columns in series, with forward vapor feed and backward pumping of liquid reflux. Product purity of 99.7% has been demonstrated, although this purity is normally not needed for styrene manufacture.

▶ **Eliminates Alkylation**—Up to now, ethyl benzene for styrene has been made entirely by alkylating ethylene and benzene. Cosden could have easily gone along with the crowd; it has benzene available on the site and could have recovered ethylene from its own field gas.

But the ethyl benzene content of the mixed xylenes—some 25 to 30% — intrigued Cosden President R. I Tollett. He put the problem up to Badger, whose engineering and economic studies convinced Tollett that fractionation, not alkylation, was the route to travel.

Badger took the project on from there. The styrene unit was completed and in operation in only 13 months. *(Continued)*

►EB to Styrene—Although Cosden is stingy with process details, Badger points out that conversion of ethyl benzene to styrene uses some new techniques.

According to conventional practice, as exemplified by the Dow process, ethyl benzene is catalytically dehydrogenated to styrene at 630 C. Steam is added to reduce the partial pressure of the reaction products. Cosden is using a catalyst containing iron, chromium and potassium oxides.

Crude product from the reactor contains about 40% styrene. This stream goes to a smaller tower for removal of benzene and toluene, then to the 185-ft.-high tower mentioned above for separation of unreacted ethyl benzene.

This latter step differs from Dow's flowsheet. Dow avoids a tall single column on the basis that, even at 35 mm. Hg top pressure, bottom column pressure and temperature would be too high, uses instead two columns of 38 and 32 plates respectively. Badger designers quite likely took advantage of recent developments in low-pressure-drop fractionation trays, such as Turbogrid or ripple trays.

Regardless of these details, however, the plant is perking right along. Within 24 hours after startup on February 11, it reached design capacity of plastic-grade styrene and is now operating above that.

Chemical Firm, Towns Join To Fight Pollution

One of the world's largest biological waste treatment plants is a-building at the Bound Brook, N. J., works of American Cyanamid's organic chemicals division.

New $4.5-million plant will treat Cyanamid's industrial waste from its 800 different chemical operations at the site and will give secondary treatment to domestic sewage of three nearby towns—Somerville, Raritan and Bridgewater, N. J. Treatment will use activated-sludge process.

Teaming up with Cyanamid, Somerset-Raritan Valley Sewerage Authority will build its primary treatment plant near the Cyanamid unit. To be on stream by 1958, both units will reduce pollution in upper Raritan River, will mean substantial savings to taxpayers.

Chloroisocyanuric Acids Leave Pilot-Plant Stage

Said to be first of its kind in this country, Monsanto Chemical Co.'s new Everett, Mass., plant for continuous production of di- and tri-chloroisocyanuric acids is expected on stream this fall.

Construction of the multimillion-lb./yr. plant signals a switch from experimental-scale process units which have been operating continuously at Everett for two years. They've been turning out small quantities of ACL-70 and ACL-75, solid chemicals with high available chlorine content, as active ingredients in dry bleaches and industrial sanitizing agents.

The two products are outgrowths of Monsanto's basic research in the fields of nitrogen and isocyanate chemistry.

Soviets Slate Plants For Fe Via Methane Reduction

Soviet Union is firming plans to build its first iron plants to reduce iron ore to iron sponge using methane gas as a substitute for coke (*Chem. Eng.*, Jan. 1957, pp. 130-134).

Actually, the Soviets admit, iron sponge production was incidental to their aim to work out a process for winning hydrogen by reacting iron oxides with methane gas. New iron plants will produce hydrogen, too.

Development work is still under way at the chemical laboratory of the Oil Institute of the U.S.S.R. Academy of Sciences. Here, ore from several deposits has been treated by the new process. Soviets claim they've achieved 90% extraction of iron from ore, after passing concentrate from reactor through magnetic separators.

Researchers estimate that cost of process installation will be half that of a blast furnace of comparable capacity.

Convention Calendar

American Society of Refrigerating Engineers, annual meeting, Hotel Fontainebleau, Miami Beach, Fla., June 3-5.

Chemical Institute of Canada, 40th annual conference, including papers on chemical engineering, chemical education, protective coatings, University of British Columbia, Vancouver, B. C., June 3-5.

American Institute of Electrical Engineers, conference on rectifiers in industry, Morrison Hotel, Chicago, June 4-5.

Forest Products Research Society, tenth national meeting, Asheville Municipal Auditorium, Asheville, N. C., June 4-7.

Manufacturing Chemists' Assn., annual meeting, Greenbrier Hotel, White Sulphur Springs, W. Va., June 6-8.

American Nuclear Society, third annual meeting, Penn-Sheraton Hotel, Pittsburgh, Pa., June 10-12.

3rd Western Plant Maintenance and Engineering Show and Conference, Civic Auditorium, San Francisco, Calif., June 11-13.

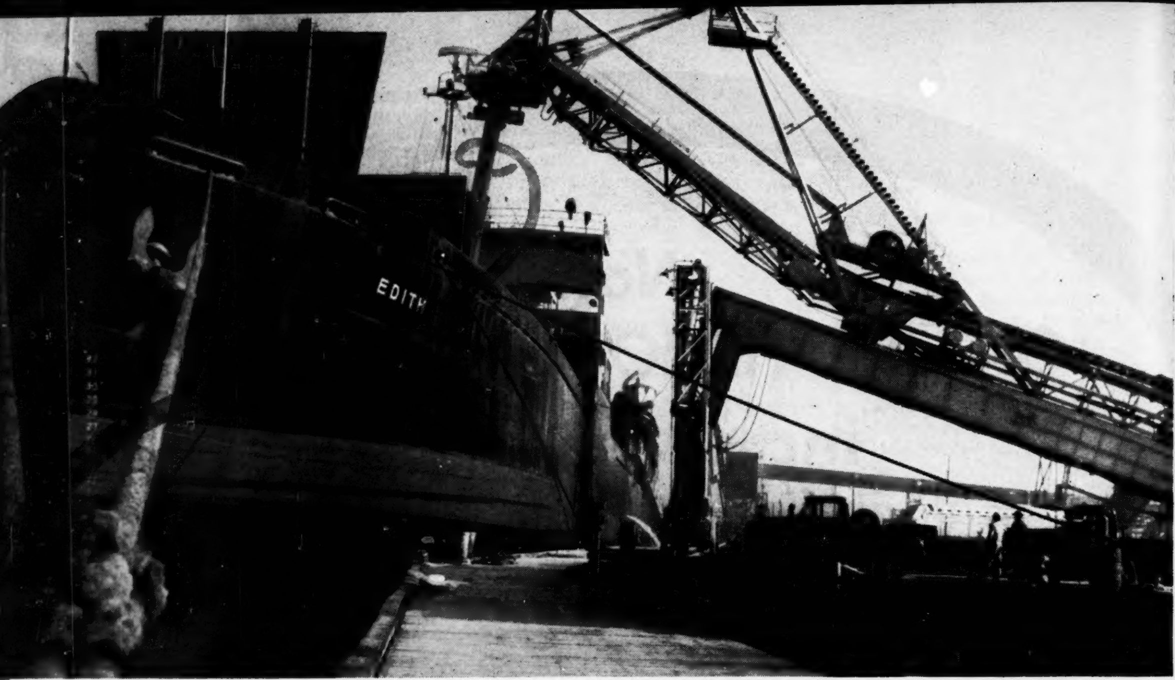
Process Control Theory, summer course, Case Institute of Technology, Cleveland, Ohio, June 11-29 (2nd session: July 15-Aug. 2).

Operations Research Conference, sponsored by Illinois Institute of Technolgy, IIT campus, Chicago, June 12-14.

American Society for Testing Materials, annual meeting, Chalfonte-Haddon Hall, Atlantic City, N. J., June 16-21.

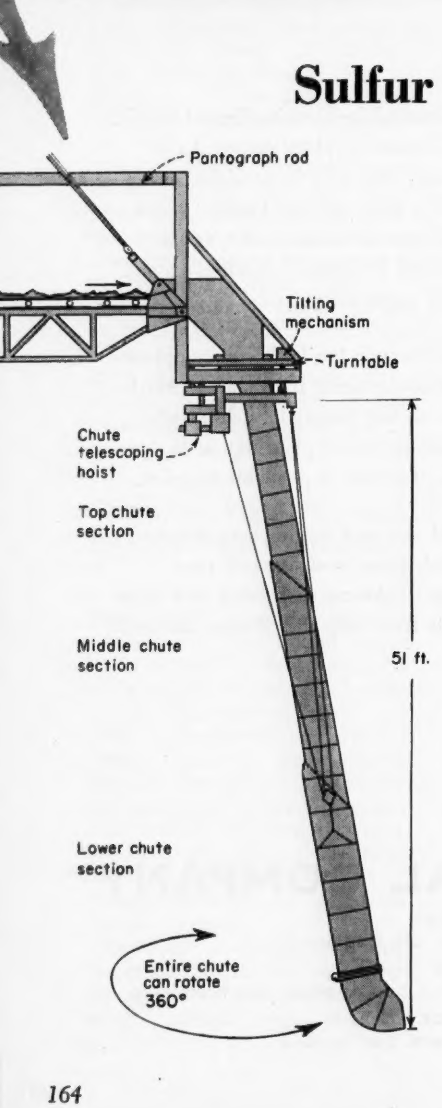
Second Industry Seminar, "Water-Derived Problems of the Pulp and Paper Industry," Institute of Paper Chemistry, Appleton, Wis., June 16-July 11.

American Association of Cost Engineers, annual meeting, Univ. of New Hampshire, Durham, N. H., June 26-29.



Sulfur Sparks New Bulk Loading Ideas

Traveling shiploader, telescoping chute conform to No. 1 demand posed by dry, dusty, combustible sulfur: Avoid all danger of flash fire from static electricity.



CIRCLED on the giraffe-like structure you see above is the key component of Freeport Sulphur Co.'s new traveling shiploader at Port Sulphur, La.

It's a special telescoping chute which successfully copes with tricky loading problems stemming from sulfur's unusual physical properties.

Designed by Hewitt-Robins and Freeport engineers, this shiploader is the latest thing for loading, quickly and efficiently, large volumes of light, bulky or dusty materials. The $1-million installation on the Mississippi River 50 miles below New Orleans is now loading sulfur at a 1,000-ton/hr. clip. And, adds Hewitt-Robins, the new design can work for bauxite, alumina, phosphates, even coal.

▶ **Danger: Static**—Idea for the telescoping chute was spurred largely by sulfur's peculiar handling properties. Though neither sticky nor abrasive, sulfur is dusty, and it readily picks up a static electrical charge. This means that rough treatment—throwing or dropping the sulfur too far—could cause a spark and touch off a flash fire.

Too, the low density of bulk sulfur demands that loading operations use all the available space in ships' holds.

▶ **Nosey Chute**—This is where the chute does its job, nosing into hard-to-get-at corners in the holds of ships and barges and gently placing sulfur in them.

The chute can rotate full circle in either direction and discharge material at all positions. It tilts through an angle up to 10 deg. with the vertical and can telescope from 33 ft. to 59 ft. below the head pulley. If it has to, it can throw material as much as 20 ft. in any direction.

▶ **Fingertip Control**—The rest of the giant structure serves to put the chute where it does the most good. Shiploader can shuttle 400 ft. along the dock, poke the chute out to 45 ft. from dockside and lift it to clear an elevation of 54 ft. Machine can move from one ship's hold to another in less than five minutes.

Entire installation is run re-

. . . from Acid to Water . . .

CB&I tanks meet wide variety of storage requirements at Western chemical plant

Eighteen Chicago Bridge & Iron Company tanks are used to store a wide variety of process chemicals for Western Phosphates Incorporated, Garfield, Utah, manufacturers of commercial fertilizers. Liquids stored in these modern welded steel units include sulphuric acid, dilute and concentrated phosphoric acid, fuel oil and water for general plant service.

CB&I is a steel plate specialist . . . with four plants completely equipped to furnish all types of steel plate structures in both standard and unique designs. Our complete designing, fabricating and erecting facilities have been serving industry for over 65 years. When you have storage problems of any kind, write our nearest office for help and information.

CB&I tanks used to store chemicals at Western Phosphates Incorporated, Garfield, Utah.

motely from a small pushbutton control box which the operator can carry on to the deck of the ship. This one man not only governs the motion of the shiploader proper, but also controls three dock conveyors and six preceding conveyor belts, totaling more than three-quarters of a mile in length.

▶**Formidable Mechanics** — While the loading chute has the flexibility of an elephant's trunk, it created some tough design problems for engineers.

Other existing sulfur chutes are attached to the boom (giraffe's neck in the picture) through a universal joint and are tilted by block and tackle tied to the ship's hatch coaming. It's a hard, time-consuming job.

A. T. Yu, Hewitt-Robins chief design engineer, and Freeport Design Engineer R. L. Bouis felt that they couldn't use a universal connection because they needed rigidity at just this point. What was needed, they reasoned, was a rigid, yet flexible, connection that would hold the chute at or near the vertical as the angle of the boom changed. They found their answer in a pantograph mechanism which keeps the chute's supporting platform horizontal at all times.

Chute's flexibility, they point out, created a lot of engineering problems for the whole structure. For one chute position, designers had to calculate two rope reactions, one pantograph reaction, five platform-hinge reactions and five boom-hinge reactions.

▶**Here Are Some Twists**—Designers came up with some novel ideas to give the loader the flexibility they needed.

Supporting the boom is a cradle (giraffe's body) riding on two sets of trucks (forelegs and hindquarters) 75 ft. apart. Engineers didn't want to sacrifice light weight for rigidity by loading down the structure with a lot of bracing between the trucks (some parts of the loader, including the chute, are made of aluminum alloy). But they had to find some way of keeping the trucks aligned so the massive cradle wouldn't be twisted out of shape.

They devised an electrical control system to synchronize the motion of the trucks. System allows a certain amount of skew in the cradle and then actuates a thruster brake on the truck most advanced in the direction the cradle is moving.

All construction in the shiploader contributes to flexibility and allows as much as a 12-in. misalignment of dock rails and a 1-deg. skew in the cradle.

An L-shaped platform, pinned to the boom and held horizontal by the pantograph rod, supports a turntable that rotates the chute. Tilting is done by a vertical screw linked to a bracket on the turntable, and a double-drum hoist is used for telescoping.

Solid engineering went into Freeport's new shiploader, and it's a good bet that other firms with materials-handling headaches will be looking at it to get ideas they can apply to their own problems.

Continuous Process Plant Will Make Methyl Butynol

Slated to be in production by fall of this year, Air Reduction Chemical Co.'s methyl butynol plant at Calvert City, Ky., will be the first in the U. S. to use a continuous process in making the tertiary acetylenic alcohol.

Process, developed by Airco research, involves reaction of acetylene and acetone over a basic catalyst.

Airco will make both methyl butynol (2-methyl-3-butyn-2-ol) and methyl pentynol (3-methyl-1-pentyn-3-ol) at Calvert City. Acetylene will come from National Carbide Div.'s nearby calcium carbide plant. Butynol capacity will be 3 million lb./yr.

Isoprenoid structure and the chemistry of the two acetylenic alcohols make them good starting materials for synthesizing flavors, perfumes, pharmaceuticals and specialty monomers. Both alcohols retain the triple bond of the parent acetylene but are themselves completely stable and cause no handling or storage problems. In addition to the triple bond, they have two other reactive points: at the hydroxyl group, and an acetylenic hydrogen.

Methyl butynol is also used as an acid-corrosion inhibitor, HCl scavenger in chlorinated solvents, brightener in metal plating and specialty solvent.

New Unit and New Process Will Synthesize Vitamins

Representing a "true total synthesis" of vitamins A, E and K, a new process developed by Hoffman-LaRoche soon will be put through its paces at the firm's Nutley, N. J., plant.

Though not yet ready to reveal process or production details, H-L does say that the starting materials for the process are acetone and acetylene. This makes the process commercially very attractive.

Ready domestic availability of the raw materials free the vitamin products from market whims of imported lemon-grass oil. Lemon-grass prices fluctuate between $1-$4/lb.

H-L has set no definite onstream date, says only that the unit is "nearing completion."

Low-Pressure Poly Spurs Fruitful Catalyst Search

Spurred by the impending boom in low-pressure polyethylene production, Metal Hydrides, Inc., Beverly, Mass., has developed new techniques to synthesize heterogeneous polymerization catalysts for ethylene.

Technique uses MHI's new sodium-hydride-in-oil dispersion of 5-25-micron particles in white mineral oil. It involves reacting sodium hydride with titanium or aluminum chlorides in the reaction vessel, then adding ethylene. This procedure avoids isolating and handling spontaneously flammable aluminum alkyls and aluminum alkyl hydrides. It eliminates laborious Ziegler technique for grinding granular sodium hydride.

MHI researchers have synthesized such catalyst systems as $NaH-TiCl_4$ and $NaH-AlCl_3-TiCl_4$.

Techniques prepare catalysts which are active at moderate pressures for polymerizing ethylene to linear, high-density polymers of molecular weights up to 300,000.

To a ball-point pen anything over 5 microns in size is a "clinker" in the ink

Removing such "clinkers" is one of many jobs for which the Sharples Super Centrifuge is ideally suited—continuous clarification of liquids, separation of two immiscible liquids, removal of solids according to particle size . . . by means of the highest centrifugual force commercially available—**13,200 x G.**

The Sharples Super Centrifuge performs many process functions at lower cost and with greater efficiency than by other means. A test run in the Sharples Laboratory may be arranged to demonstrate this superior performance.

We'll be glad to send you a copy of Sharples Bulletin 1248.

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Associated Companies and Representatives Throughout the World

POLYSTYRENE warehouse typifies Dow's faith in pole-type buildings.

Poles Furnish Cheap Support

. . . for roof and walls of plant buildings, eliminate the usual foundations as well, yield a sound, durable structure at a fraction of normal building cost.

A new, low-cost type of building which first appeared on the industrial horizon about two years ago now dots the landscape in increasing frequency.

Based on the use of treated wood poles, these buildings are providing warehouses, office space and even space for processing. Dow Chemical has built four at Midland, Mich., contemplates more; industry total is well up in the hundreds.

▶ **Selling Points**—Using firmly planted, strategically located utility poles to replace framework, foundation and roof supports, the buildings are usually enclosed with aluminum or galvanized steel. Major advantages are:

• *Low cost*—One new Dow building, 126 x 261 ft., for storing plastic materials, was erected by an independent pole-building contractor for $1.43/sq. ft. (This did not include a specially prepared crushed-rock floor or the sprinkler system.) A more conventional warehouse would have cost two or three times as much. In general, this type of construction gives two to three times the available work and storage area for your construction dollar.

• *Speed of erection*—There have been many field reports of small crews starting a 2,400-sq.-ft. structure on Monday morning and having it completed by Saturday. Strength of the anchored poles reduces the amount of building materials required. Labor costs are cut to a minimum, and construction time is speeded up accordingly.

• *Durability*—Commercially treated with a permanent wood preservative, such as pentachlorophenol, poles last as long as the other materials in the building. Baseboards are also treated with a preservative. The buildings are highly wind-resistant because the poles, imbedded 5 ft. in the ground, provide firm anchorage. Siding and rafters are nailed solidly to the poles, and this, in turn, gives the walls and roof strong support.

• *Flexibility in design*—Since the roof is completely supported by the poles, any inside partition can be moved or eliminated after the building is completed. Any part of the building can be finished off for office or sales areas. Remodeling or expansion is quick and simple.

▶ **How Firm a Foundation**—Chief difference between a conventional and a pole-type building is in the foundation. Poles similar to the usual utility pole, placed in the ground at the perimeter of the building and set at proper positions throughout the interior, form the foundation. These foundation poles can be installed more quickly and at lower cost than the usual foundations.

In addition, complicated framing and other expensive elements found in conventional buildings are largely eliminated. A minimum of sawing and framing is required. When used for bulk storage, the strength of the poles themselves gives excellent rigidity against heavy side pressures.

Acceptance of the pole-type building by the farmer a decade ago created a demand for specialized contractors who could erect the structures quickly and efficiently. Originally considered suitable only for farm use, pole-type construction now appeals to businessmen and engineers as one effective way to fight rising construction costs.

▶ **Number Five Going Up** — Dow's first pole-type building, for titanium processing and storage, was completed last September. Height is 30 ft. at the peak, requiring some poles as long as 35 ft. It is 67 x 91 ft., contains a 6-in. reinforced concrete floor, has aluminum roofing and siding.

Two months later the company completed a pole-type tank-car coating shed. Main building is 20 x 50 ft. with a 14 x 24-ft., completely enclosed, attached heater house. Here, tank cars receive several types of interior linings to prevent contamination of products or corrosion of the cars. On three sides of the floorless building, aluminum siding extends only halfway to the ground.

In March, the latest and the largest Dow pole buildings were completed: the plastics storage building mentioned earlier; and a 76 x 154-ft. pole building for transient storage of phenol prod-

ucts was completed at a cost of \$2.86/sq. ft. (This cost figures in a 6-in. reinforced concrete floor but not the sprinkler and electrical systems.)

Dow's immediate plans for more pole-type buildings include a large calcium chloride warehouse to be constructed this summer.

U. K.'s Hinton Projects Cost of Nuclear Power

Speculation over gas-cooled nuclear reactor economics has been keen ever since Britain's Calder Hall power station swung on stream (*Chem. Eng.*, Dec. 1956, pp. 114-116).

Now U. K. Atomic Energy Authority's Sir Christopher Hinton has just provided a detailed cost estimate of such electrical power generation. From his figures, this kind of reactor proves to be surprisingly competitive. And striking cost reductions are promised for the future.

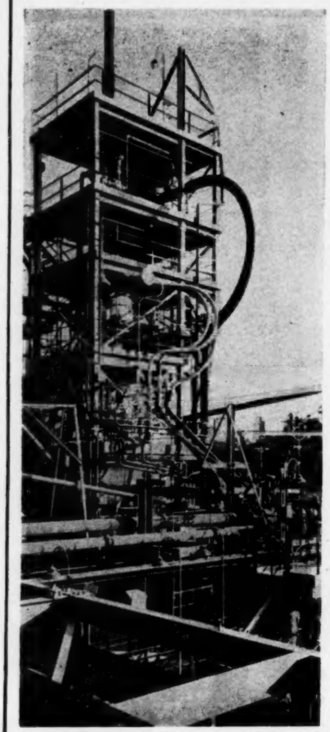
Hinton puts reactor's present generating cost at 6.6 mills/kwh., as compared with conventional installations' 6 mills/kwh. By 1990, gas-cooled reactors should produce electricity for 3.2 mills/kwh., while generating costs of conventional plants will have climbed to 8.4 mills/kwh.

▸**Cheaper in Six Years** — In fact, Hinton predicts, nuclear stations on stream in 1963 will already show cost advantages over fossil-fuel-fired stations.

These figures refer specifically to reactors uprated and optimized for power generation. They don't apply to Calder Hall itself, whose reactors are derated and optimized for plutonium production. Calder Hall's costs are under AEA security wraps to avoid revealing Britain's plutonium output.

Here's Hinton's cost breakdown per kwh. generated: 3.7 mills capital cost (interest and depreciation), 0.6 mills fuel interest charge, 0.6 mills operating cost, 2.4 mills fuel-replacement charge. And then there's a 0.7-mill credit for byproduct plutonium.

Comparable breakdown for conventional plant runs 1.2 mills for capital, 1.2 mills for fuel and 4.4 mills for operation.



New Look in TEL

Just on stream is Du Pont's new multimillion-dollar tetraethyl lead plant at Antioch, Calif., near San Francisco. In center of the picture is reactor tower using continuous process—more efficient than the old batch process—to make TEL.

To put these numbers in an American frame of reference it's useful to note how the British—with nationalized industries, etc.—figure their costs. Capital charges are based on a 5% interest rate over a 20-yr. life. Fuel costs run \$56,000/ton, with interest charged at 5%. Fuel utilization averages out to 1,500 days/ton.

Biggest cost reductions will come in capital charges—from present 3.7 mills to 2.2 mills by 1990. Primary technical factor: Higher gas temperatures will be permissible, allowing higher steam temperatures and better thermal efficiencies.

News Briefs

Silicones: Minnesota Mining & Mfg. is putting in a pilot plant at Hastings, Minn., to make silicones. It won't start cold on raw materials but will use intermediates.

Sodium borohydride: Metal Hydrides, Inc., Beverly, Mass., has been awarded a \$9.2-million contract by U. S. government for delivery of sodium borohydride. New plant now under construction at Danvers, Mass., will produce the hydride for the government's high-energy-fuel program.

Ethylene dibromide: Newly established Dead-Sea Bromine Works, Ltd., will turn out 1,800 tons/yr. of ethylene dibromide under patent rights acquired from a German chemical concern.

Aluminum: Three companies, Kaiser, Reynolds and Aluminum Co. of Canada, are planning expansion in production or processing of aluminum: Kaiser—Aluminum foil plant, Belpre, Ohio, \$2 million; Reynolds—\$150 million for primary aluminum plant near St. Lawrence Seaway project; Alcan — \$125-million public debenture offering for 10-year expansion program that will double capacity.

Acrylonitrile: Monsanto Chemical Co. and Carbide & Carbon Chemicals Co. both plan boosts in acrylonitrile production. Carbide will double output at its Institute, W. Va., plant by the second quarter of 1958. Monsanto is boosting capacity at Texas City, Tex., to 100 million lb./yr.

Semicellulose: Austrian scientist Karl Schuler has made public data on a new process claimed to produce whitish semicellulose usable in manufacture of all but the finest grades of paper. Commercial value of the process, says Schuler, is that from a given amount of raw material twice as much semicellulose can be derived at equal quality as can sulphite-type cellulose.

Where lead gives useful corrosion control

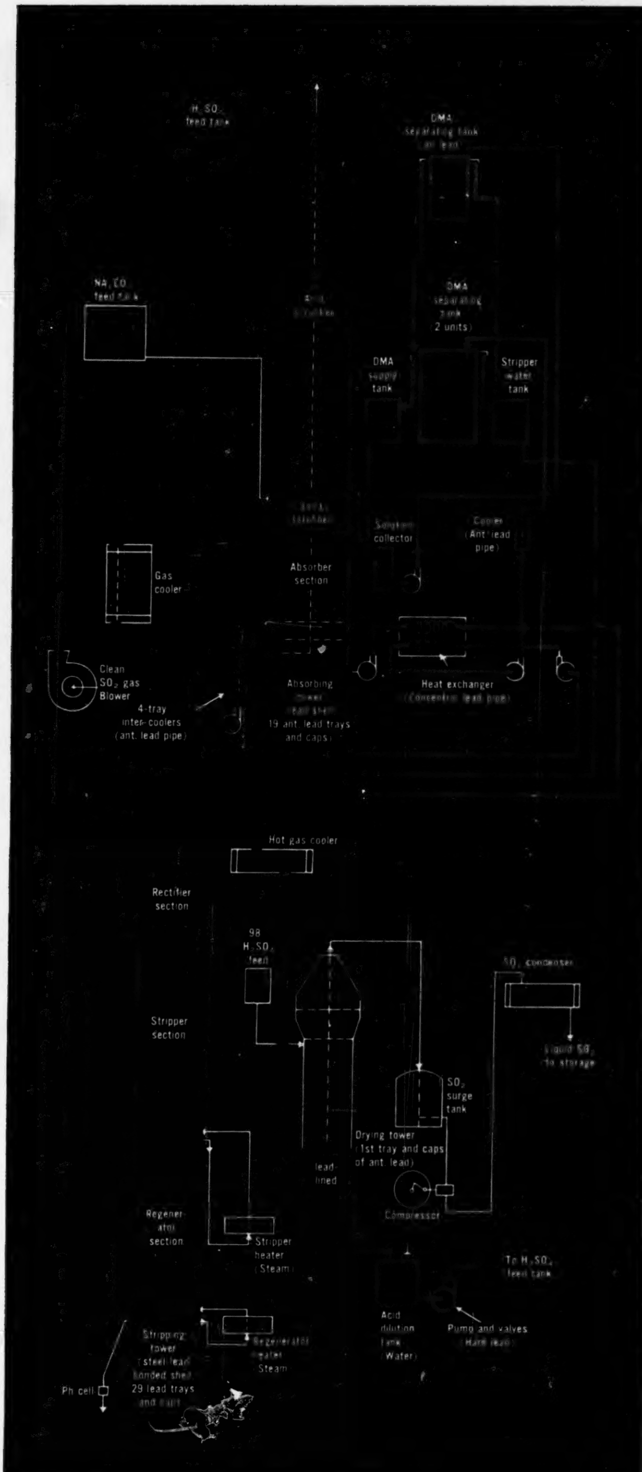
in liquid Sulphur Dioxide process vessels and piping

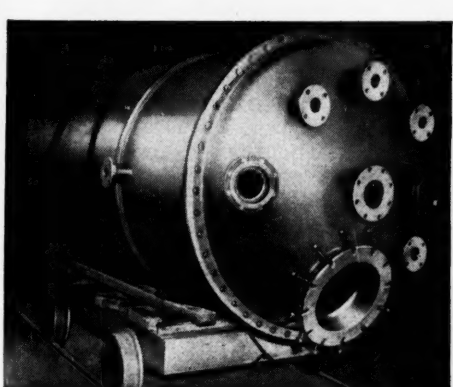
Hot SO_2 vapors and other oxidation products present in liquid SO_2 processing are "murder on metal." Even that old corrosive marauder, H_2SO_4 gets into the act.

As a result, *lead* practically lives with these acids and gases throughout the SO_2 process. In fact, the flow chart at the right is almost a continuous flow of *lead* applications. For ducts. For piping. For sheet lead linings in the larger units like the scrubbers and strippers. It is used with steel, with wood, with copper and, in some cases, with concrete. The result is low maintenance cost, facility of repair and consequent freedom from costly production stoppages.

If your process involves corrosive chemicals, look to *lead* for *long life, low maintenance and minimum loss of production due to down-time.*

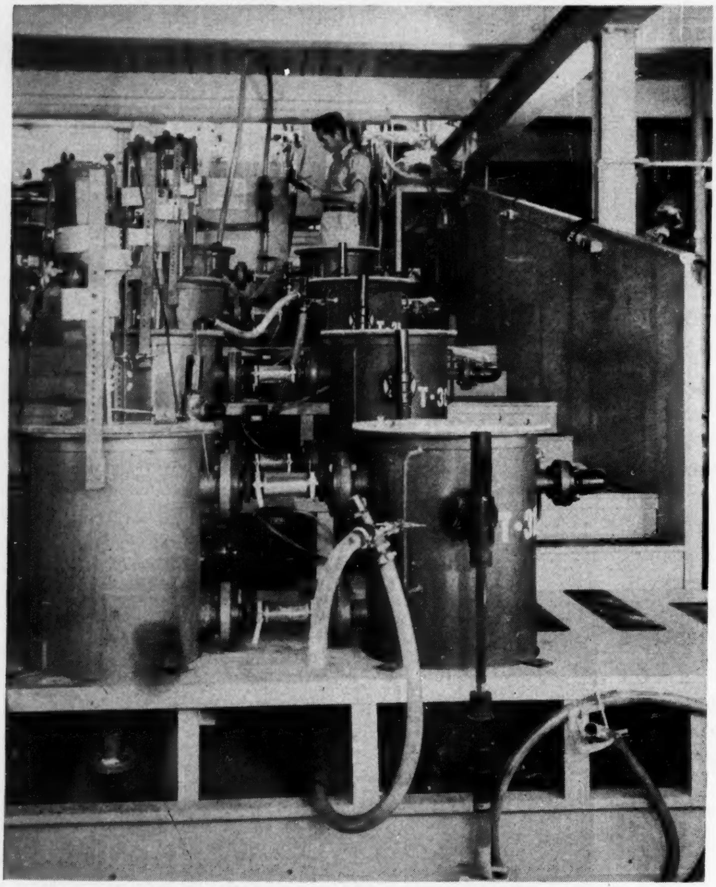
When you think of Lead ...*think of* National Lead





National Lead has the experience to get *lead* and steel together in a *bond* that defies severe pressure and temperature changes, vibration and creep. That's been proved not only in regular production "stock" items such as piping and valves but also in specially designed, complex lead process and storage equipment.

If you are enlarging or modernizing your processing facilities, now's a good time to get the facts about lead-lined equipment. Contact National Lead Company, Lead Lined Products, 111 Broadway, New York 6, New York.



SOLVENT EXTRACTION gains ground in uranium processing with . . .

Better Uranium Extractants

Two new alkyl phosphate esters are permitting uranium processors to capitalize on solvent extraction's inherent advantage of simple continuous operation.

Effectiveness of two new alkyl phosphate esters as selective solvents for the extraction of uranium creates a better industry-wide competitive position for the extraction method vs. ion exchange.

Dow Chemical Co. is currently offering: Dowsol 12, the monododecyl phosphoric acid, known as DDPA, on a commercial basis; Dowsol 17, the heptadecyl phosphoric acid, on a developmental basis. They are the first of a family of solvents to be offered by Dow not only for uranium processing but for other metal processing such as recovery of vanadium, thorium and other base metals.

Compared to older solvents, both offer: higher uranium coefficients, lower water solubility. But on both these counts, Dowsol 17 is believed to excel even Dowsol 12. In addition, Dowsol 17 can be stripped by the use of carbonate whereas hydrochloric acid is recommended for stripping uranium from Dowsol 12.

Dowsol-12 is supplied as a 25-30% solution in kerosene. For use in metal recovery, it is diluted with kerosene to a concentration of from 2-5% alkyl ester. This mixture of Dowsol-12, the extractant, and kerosene, the carrier, is termed the solvent. Dowsol-12-kerosene solutions are immiscible with aqueous solutions, slurries, or pulps.

When this solvent is contacted with a solution containing metal values, the values are transferred from the solution to the solvent. The barren solution and loaded solvent resulting from such contact are separated by settling due to specific gravity differences. After separation, the solvent is stripped of metal values by contact with strip solutions and the solvent reused.

Various stripping solutions are suitable for the different metals. For uranium 10 molar hydrochloric acid is recommended. The pregnant strip solution can be evaporated to yield a concentrated solution of uranyl chloride and hydrochloric acid suitable for reuse in stripping.

Vanadium is stripped with one molar sulfuric acid and a red cake product precipitated from the strip solution by conventional methods. Thorium fluoride can be precipitated directly from the solvent by an acid fluoride solution.

Reactions involved with Dowsol-12 are cation exchange in nature. The general reaction is:

$$RPO(OH)_2 + M^+ \rightarrow RPO(OH)OM + H^+$$

Extractability of metals increases in general with increasing valence of the cation. The complexing action of the phosphate group makes the solvent quite selective for cations such

Newsworthy chemicals this month

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as UO_2^{+2}, U^{+4}, VO^{+2}, and Th^{+4} compared to other cations. Fe^{+3} and Al^{+3} interfere to slight degree.

Dowsol-12's chemical name is mono-[1-(2-methyl propyl)-3, 5-dimethyl-hexyl] phosphate. It's molecular weight is 266. Current price is $1/lb. of active ingredient fob. Pittsburg, Calif. —**Dow Chemical Co., Midland, Mich.** 172A

Polystyrene

New molding compound improves breakage resistance of thin walls.

SMD-3700 Crystal 11 is a new free flowing polystyrene injection molding compound specifically developed for thin walled parts, such as containers and lids, and for intricately designed, long flow parts which tax machine capacity.

This material is designed to flow easier into mold cavities at lower cylinder temperatures or pressures and on faster cycles than general purpose polystyrenes. It can be molded over a wider range of cylinder temperatures, and is freer flowing than general-purpose polystyrenes at all of these temperatures.

SMD-3700 can be molded at cylinder temperatures between 350 F. and 650 F., depending on the part and the cycle. Mold temperatures for the materials are sometimes slightly lower than are used for general-purpose polystyrenes. The normal range of injection pressures, 10,000 to 20,000 psi., is often more than adequate for the material.

Parts molded from SMD-3700 exhibit reduced strain as compared to similar parts molded from general-purpose polystyrenes. SMD-3700 thin wall parts, particularly, are less highly strained in the direction of flow, and hence have greater strength across the lines of flow, the direction in which a molded container or thin walled part is weakest.

The compound is available in cylindrical pellets 0.1 by 0.1 in. and in a fine granulation for dry coloring. In crystal form it is free from color and has excellent clarity. It molds with the same hard glossy surface as does general-purpose polystyrene. It can be printed or coated by the same techniques as are used for other polystyrenes.—**Bakelite Co., 260 Madison Ave., New York 16, N. Y.** 174A

For More Information . . . about any item in this department, circle its code number on the **Reader Service** postcard inside the back cover

Black Polyethylene

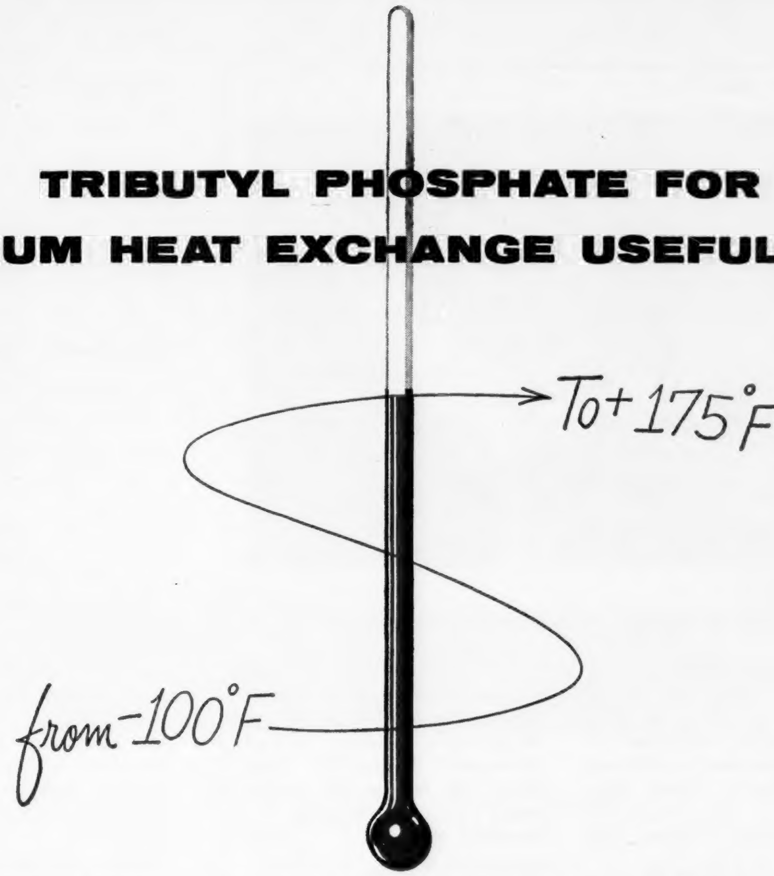
Now available as a film and paper coating resin for outdoor use.

Alathon 5F polyethylene resin is a new high-quality black formulation, commercially available as a film and paper-coating resin for applications where resistance to outdoor weathering is important. Products extruded from it are said to be notably free of pinholes and surface defects. Complete dispersion of carbon black in film insures greater protection against degradation caused by sunlight.

A medium-density material, Alathon 5F is intermediate also in stiffness, toughness, yield strength, impermeability, etc. The dispersion of carbon black in the resin is comparable to that found in the best black film used in electrical applications. Melt index is well within the range commonly found in film and paper coating resins. It is easily extrudable, nontoxic. Price is 37½¢/lb. in truckload quantities.

Its most dramatic application to date is in the experimental

TRIBUTYL PHOSPHATE FOR MAXIMUM HEAT EXCHANGE USEFULNESS...



As a fluid heat exchange medium, Tributyl Phosphate is notable for being useful over such a wide range of temperature.

When compared with aqueous solutions and halogenated compounds, TBP offers many unique advantages. It is non-corrosive, non-flammable, non-volatile and is of a low order of toxicity.

Calcium chloride solutions, although sometimes used at low temperatures, are highly corrosive and cannot be inhibited. Glycol solutions are too viscous to use below –50°F, and most other organic compounds which can be used below –50°F are unsatisfactory from a standpoint of toxicity, volatility, flammability and corrosive properties.

Tributyl Phosphate has been satisfactorily tested as a heat exchange medium within the range of –100°F to +175°F. With its high boiling point (351°F at 27 mm), it is most useful in multi-purpose systems where heating may follow a cooling cycle. In addition, TBP has a high density of 0.97 g/ml which requires a smaller volume than some other liquids.

At –94°F, the viscosity of Tributyl Phosphate is 296 centipoises and available data indicates that the viscosity at –120°F would be around 1000 centipoises. Since centrifugal pumps can easily accommodate a liquid of 1000 centipoises, and even 3000 if necessary, TBP should be useful even as low as –120°F.

Write today for sample, technical data sheet and for information on utilization of TBP in brine-type refrigeration units and other heat exchange systems.

Physical Properties

Specific Heat	0.43 cal/g (0.76 Btu/lb.)
Molecular Weight	266.316 (calc.)
Boiling Point at 27 mm	177°-178°C
Freezing Point	<–80°C
Density at 25°C	0.972
Weight per U.S. gallon at 68°F	8.19 lb.
Coefficient of Expansion	0.00052 per 1°F
Refractive Index, n_D at 25°C	1.422
Viscosity at 77°F	3.41 cp
–94°F	296.0 cp
Latent Heat of Vaporization	55.1 cal/g
Dielectric Constant at 30°C	7.959
Flash Point, Cleveland Open Cup	294°F
Solubility in water at 25°C	<1% by volume
Solubility of water in Tributyl Phosphate at 25°C	6.55% by volume

INDUSTRIAL CHEMICALS DEPARTMENT

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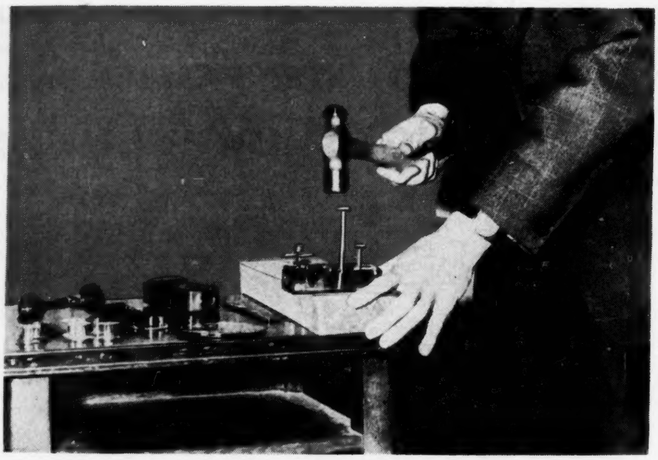
DISCOVER THE NITROPARAFFINS!



New "Tough as Nails" Polycarbonate Plastics

Brand new family of plastics, the polycarbonates, are strong enough to make nails for driving into lumber. Developed almost simultaneously by GE and Germany's Beyer (*Chem. Eng.*, May 1957, p. 144), they excel older competitive resins, and cellulosics, in tests of impact resistance. They also outstrip most of the competition in tensile strength, resistance to heat distortion. Ultimately, their price may fall in the 50¢/lb. range. — General Electric Co., Pittsfield, Mass. 176A

solar distillation unit designed by Du Pont in conjunction with a program conducted by the Dept. of Interior to utilize the sun's energy in converting salt water to fresh water. The heavy black plastic base or evaporation pan is composed of Alathon 5F, making large scale economical distillation of saline water more of a commercial possibility. In most climates, life expectancy of film made from the new black polyethylene is from two to four years.

Other suggested applications for the new polyethylene formulation are conveying and storage of irrigation water; protection of harvested crops, mechanical equipment, construction materials and other perishables from weather; ground mulches for such crops as pineapples, strawberries, beans and tomatoes; vapor barriers to retard the evaporation of water during the curing of concrete; light barriers for use in packaging sensitive materials; water-resistant construction papers; and as gas barriers in soil fumigation.—**Du Pont Co., Wilmington, Del. 174B**

And Bakelite has a black mulching film made from specially formulated polyethylene. Tests made on it at Kentucky's Agricultural Experiment Station showed that it more than pays for itself in the first ten weeks of the growing season by forcing produce to early maturity. In addition, the black-mulched part of an experimental garden at the station was weedless and vegetables grown there were bigger and healthier.

Clear films worked as well as opaque ones in retaining soil moisture and in keeping ripening fruit from coming in contact with moist ground where mold rot and disease start. But opaque films had the added virtue of curtailing the growth of weeds. Under clear polyethylene films, weed growth was luxurious unless the soil was first treated with a chemical weed killer. Of the variously pigmented polyethylene films, black appeared the most durable when mulches were left in place for more than one season's use. — **Bakelite Co., 260 Madison Ave., New York 16, N. Y. 174C**

Menthane Diamine

Promises use in epoxy and polyurethane manufacture.

Menthane diamine has been added to Rohm & Haas' t-alkylamine series. It is available in pilot plant quantities at the company's standard development price of $2/lb.

The new product is expected to prove useful as an epoxy resin curing agent and a raw material for polyurethane manufacture after conversion to the diisocyanate. The compound will also undergo most of the reactions typical of the amino group. Reaction with dibasic acids or anhydrides to form polyamides or use in various organic syntheses (preparation of dyes, inhibitors, rubber accelerators and medicinals) show commercial promise.

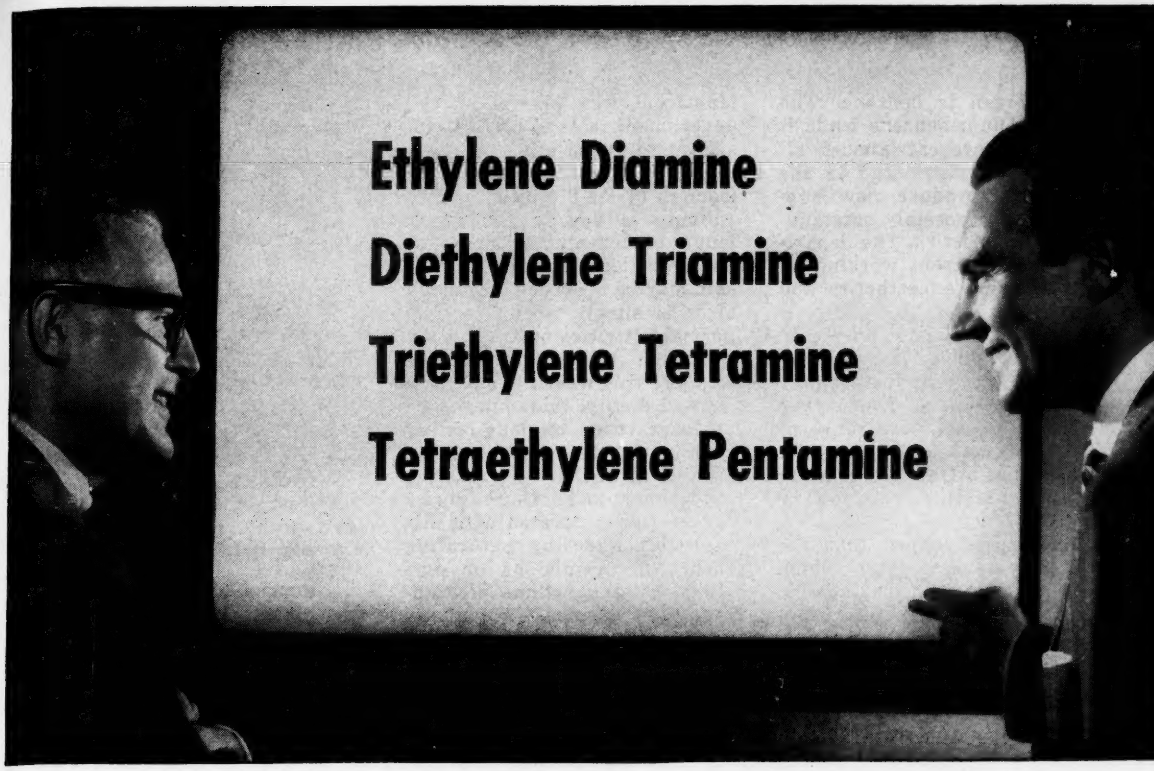
Other products in the t-alkylamine group which the company introduced in 1951 include t-butylamine, t-octylamine, Primene 81-R and Primene JM-T, all available in tankcar quantities.—**Rohm & Haas Co., Washington Sq., Philadelphia 5, Pa. 176B**

Fluorine Compounds

Range of newly-synthesized products boast great chemical stability.

The chemistry department of Birmingham University in England may soon provide the chemical industry with fluorine compounds from which can be produced a great many versatile, relatively non-flammable materials such as fibers for textile, lubricants and plastics of great strength and durability.

Recently the department has been able to substitute fluorine



With Carbide's Ethylene Amines you're not limited in **CHOICE** *or* **AVAILABILITY**

That's right—CARBIDE produces all four of the commercial ethylene amines as distilled, high quality products.

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for hydrogen in benzene. The resulting fluor-benzene made it possible to repeat almost all coal tar chemistry and in the process to produce new substances with possibly outstanding characteristics. The department is at present working on nonflammable anaesthetics and new drugs.

These new products have been made possible by the development of gas chromotography equipment (*Chem. Eng.*, June 1956, p. 116). A wide range of fluorine compounds, one of whose chief attractions is great chemical stability, can now be made.

In spite of hopes that the British Government, which helps to subsidize this research, will provide money for establishing pilot plant production, the essential bridge between research and industry is lacking. British industry is very interested in the research, but the department finds it impossible to provide new materials in sufficient quantities for industry to carry out tests on the necessary scale. — **Birmingham University, Birmingham, England.** 176C

Diethyl Toluamide

"The best all-purpose insecticide so far developed."

Dept. of Agriculture has released for commercial use what it says is the best all-purpose insect repellent so far developed — diethyl toluamide. Closely following, Montrose Chemical Co. announced that it is offering a high concentration meta isomer of diethyl toluamide to formulators of insect repellent lotions and similar preparations.

A product of research by USDA in cooperation with the Dept. of the Army, DET can be applied directly to the skin or clothing and protects the user against mosquitoes, ticks, chiggers, fleas and biting flies for up to 8 hr. USDA reports that it is more effective against mosquitoes generally than any other single chemical or combination of chemicals.

The meta isomer, offered by Montrose, was shown in the government tests to be most resistant to "wipe off" and gives longer protection than other isomers of DET. Resistance to rubbing is one of the repellent's best features. Some of any repellent applied to the skin may be absorbed, but much of it is simply worn away by normal activities of the wearer. A "wipe test" developed to measure this wearing-off action showed diethyl toluamide to be at least twice as long-lasting as the next best repellent, according to USDA.

Clothing and other fabrics can be readily treated with diethyl toluamide by saturating them with emulsions or drycleaning preparations containing the chemical. — **Montrose Chemical Co., Newark, N. J.** 178A

Actinium

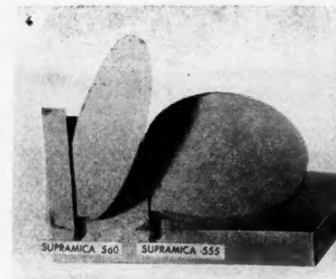
Now artificially produced for use in radioactivity well logging.

Artificially produced actinium has been put to work by the oil industry in their search for oil. The separated actinium is mixed with beryllium to make the actual source needed for the oil industry's neutron logging operations.

The source, made from the separated actinium, has been on field test with the oil industry service companies and has displayed anticipated characteristics of stability and safety.

Radioactivity well logging makes use of naturally occurring and induced nuclear radiations to obtain useful information regarding the formations penetrated by a borehole. A neutron log is obtained by moving along the well an instrument containing a source emitting energetic neutrons while a radiation detector spaced a fixed distance from the source measures the response of the formations to the neutrons.

Actinium was selected for artificial production because its extremely long half-life, its high neutron emission vs. a low gamma ray emission all contribute to success in this application. And it's adaptable to logging instruments small enough to pass through two-inch drill pipe.—**Well Surveys, Inc., Tulsa, Okla.** 178B



Ceramoplastic

Supramica 560 resists higher heats than older synthetic - mica - containing compounds.

A new moldable ceramoplastic insulating material, known as Supramica 560, will withstand continuous operating temperature in excess of 932 F. Laboratory and industrial tests indicate that short time operating temperature will be in the neighborhood of 1,200 F., depending on the mass and configuration of the part.

The new product, which includes synthetic mica, retains the electrical properties common to manufacturer's older synthetic - mica - containing ceramoplastics like Supramica 555 (see cut). And it features considerably lower density in addition to its increased thermal endurance.

The specific gravity of Supramica 560 has been reduced to 2.8, only slightly higher than that of mineral-filled alkyds and polyester glass compounds. The combination of lighter weight and greater thermal endurance shows great promise in the development of high-temperature, quality components for airborne and missile applications, and for other equipment in which reliability under extreme conditions is of utmost importance.

The compound can be precision-molded to very close tolerances and is dimensionally stable during and after fabrication. Because of thermal expan-

Parts in process can be

PROTECTED FROM CORROSION

with SOLVAY SODIUM NITRITE

Parts in process are protected against rust if you treat them with an inexpensive, low-concentration solution of Solvay Sodium Nitrite. Both of the gears above were stored under *identical* conditions of high humidity—the gear at the right was protected by dipping in a 3% solution of Solvay Sodium Nitrite before storage.

Solvay Sodium Nitrite prevents corrosion on metal surfaces by forming an invisible gamma oxide protective film. It can be applied in solution by dipping or spraying, or can be added to the water in circulating systems. It is effective with iron and steel, and is reported to suppress the degradation of aluminum, tin, monel, copper and brass. It can be combined with caustic soda or phosphates for increased protection during or following cleaning, neutralizing or other operations. Easy to apply . . . Solvay Sodium Nitrite is non-toxic in concentrations normally used for corrosion prevention.

For a working sample and complete details of Solvay Sodium Nitrite's adaptability to a wide range of anti-corrosion uses, mail the coupon promptly.

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Monochlorobenzene • Para-dichlorobenzene • Vinyl Chloride • Ortho-dichlorobenzene • Hydrogen Peroxide
Methylene Chloride • Carbon Tetrachloride

SOLVAY®

Properties of Supramica 560

Dissipation factor at 1 meg.	0.0035
Dielectric constant at 1 meg.	6.8
Loss factor at 1 meg.	0.024
Volume resistivity, ohm-cm.	5×10^{13}
Specific gravity	2.8
Water absorption, 24 hr.	Nil
Hardness (Rockwell M)	125
Thermal expansion, @ 20° C.	13×10^{-6}

sion coefficients closely matching those of steel, functional or reinforcing inserts may be molded in without risk of loosening and resultant corona. —**Mycalex Corp., Clifton, N. J.** 178C

Behenic Acid

High-purity, long-chain fatty acid stabilizes emulsions.

Behenic acid, a saturated C-22 chain length fatty acid, is now available in carload lots. Longest straight chain fatty acid commercially available from natural fats or fatty oils, it can be esterified with fatty alcohols to produce high melting point waxes. Because it stabilizes emulsions, this material is ideal for soaps, lotions, cosmetics, lubricants, chemical intermediates, esters, stabilizers and specialties.

It is a white waxy, almost odorless crystalline solid at room temperature. Due to the high melting point it is slightly soluble at room temperature but soluble in following solvents at their boiling points: ethyl alcohol, isopropyl alcohol, acetone, benzene, chlorinated solvents. — **Archer-Daniels-Midland Co., 700 Investors Bldg., Minneapolis, Minn.** 180A

Defoamer

New liquid eases processing of latex paints, paper coating.

A new liquid defoamer, Surfynol 104A, has shown excellent results in aqueous systems where foaming is a process problem.

Like the manufacturer's other Surfynols, 104A is a ditertiary acetylenic glycol, a class only recently recognized as low-foaming, nonionic surface active agents. The new addition to the line is the first of these to be developed specifically for defoaming. Surfynols 104A and the older 104E are solutions of Surfynol 104 in 2-ethyl hexanol and ethylene glycol, respectively. Both liquid Surfynols are 50% active.

Some successful applications are in latex paints, coating and resin sizing of papers, textile sizing, metal cleansers, starch and protein adhesives and low-sudsing detergents. However, in systems where the odor of the octyl alcohol may be objectionable, it is suggested that 104E be used.

The Surfynols, in nearly all cases, when combined with a foaming surface active agent, either nonionic, anionic or cationic, give synergistic surface activity and reduce or completely eliminate foam. The liquid Surfynols are therefore suggested for use in combination with other surfactants to increase surface activity without creating foaming problems. —**Air Reduction Chemical Co., 150 East 42nd St., New York 17, N. Y.** 180B

BRIEFS

Polyethylene blended with new exceptionally hard, high-melting point, coal-derived wax (Chem. Eng., Apr. 1957, p. 180) shows improvements for injection molding of plastic items. A 10% blend in 20,000 m.w. high pressure polyethylene showed a melt index of 5.8 g.; the 20% combination, 15.6; a 30% blend 47. Unblended polyethylene had a melt index of 1.98.—**Moore & Munger, 33 Rector St., New York 6, N. Y.** 180C

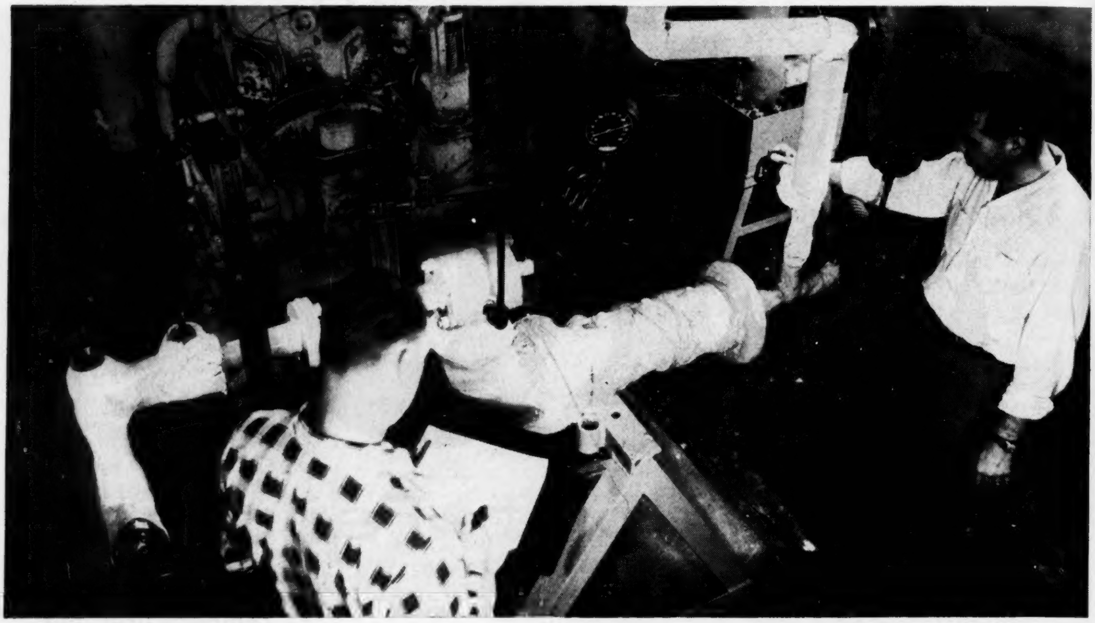
Epoxy potting and casting system, called Hysol 6900 series, brings together economical price, several steps of flexibility, low heat cure and ease of handling. Sold in two-component units in three sizes, the series currently includes both filled and unfilled versions with two degrees of flexibility of each type. Moderate cure at 75 C. permits encapsulation of delicate, temperature-sensitive electronic components. — **Houghton Laboratories Inc., Olean, N. Y.** 180D

Detergent motor oil additive, No. "7" M.O.A., may halt sludging of automobile engines in stop-and-go driving. It works in the presence of water by enveloping sludge particles with a water-resistant coating. They remain suspended in oil, easily pass through oil screen and filter and are drained off when oil is changed.—**Du Pont Co., Wilmington, Del.** 180E

Fungicide and rubber accelerator are applications earmarked for new form of tetramethyl thiuram disulfide. It boasts high purity (99½%) and activity plus micronized particle size.—**Aceto Chemical Co., 40-40 Lawrence St., Flushing, N. Y.** 180F

Two new viscosity index improvers for lubricating oils are being offered. Called Omavis 10 and 20, the additives are outstanding in their resistance to shear breakdown. Light colored, viscous solutions of polymers in oil, the two products are identical chemically but differ in molecular weight of the active ingredient. — **Olin Mathieson Chemical Corp., 460 Park Ave., New York, N. Y.** 180G

Chemical synthesis of penicillin, important scientifically, less so commercially, has been achieved at MIT. While the new chemical method probably will not be cheap enough to compete with the established fermentation process, it has made it possible to test ten synthetic penicillin analogs. It is hoped that new forms will prove effective against disease organisms now resistant to natural penicillin and against a wider variety of infections. New penicillins might also have less tendency to produce allergic reactions.—**Massachusetts Institute of Technology, Cambridge, Mass.** 180H



Combustion-Gas Ejector Cuts Pumping Cost

High-release burner produces high-energy motive fluid that improves ejector performance and drops cost below air or steam ejectors, in many cases.

In this era of mergers, engineers are also getting into the act. In a recent technological advance, ejector specialists have teamed a burner with an ejector to broaden the field of ejector applications. Key step in the development was the successful design of an ejector inlet nozzle to expand the gas as required.

At Graham Mfg. Co., Batavia, N. Y., this new design and concept have been proven thoroughly in extensive trials. Designs have been completed on a mammoth installation to evacuate a jet-engine test cell.

But even more interesting to industrial users are the prospects of applying the gas ejector to process needs. Unless a plant has sufficient waste steam to fill ejector requirements, the gas ejector can be installed and operated for less over-all cost than either the air or steam types. In refineries, where there is ample fuel gas and 40-70-lb. air, these ejectors are ideal.

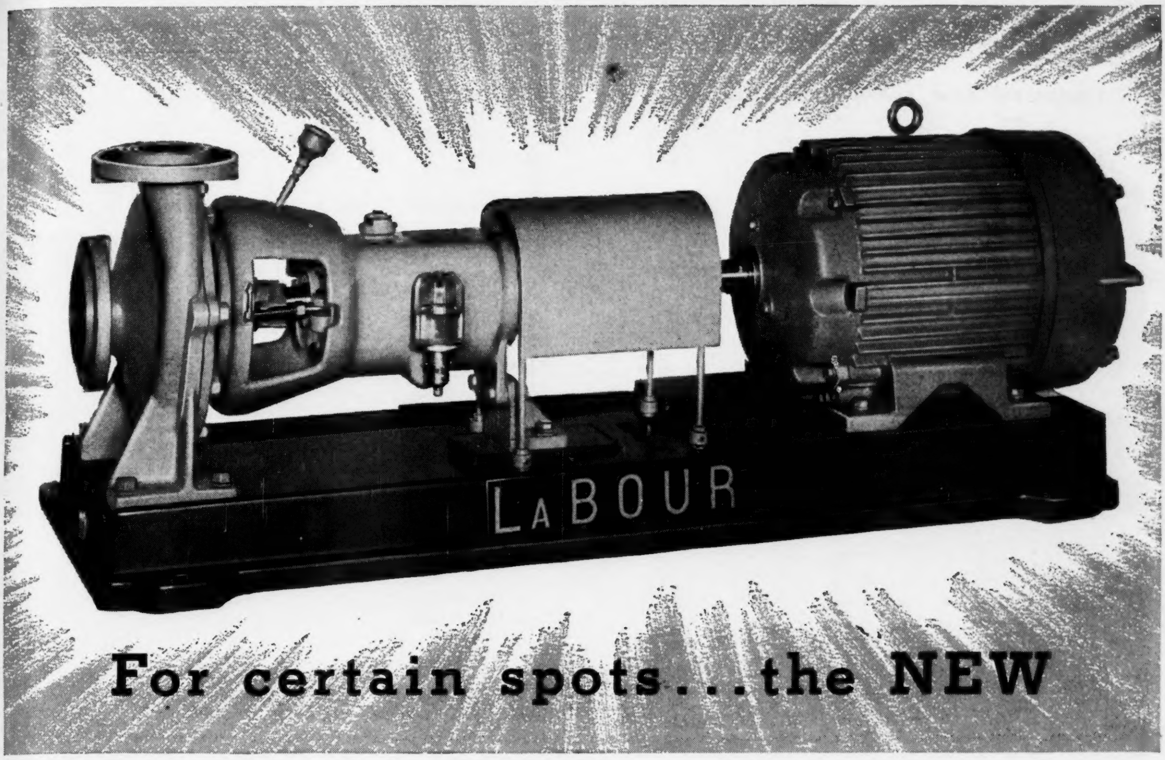
▶**Equal to Steam**—Gas ejectors will operate over the same range as steam ejectors. Unlike steam ejectors, they do not use interstage condensers. The entire output of the ejector is discharged to atmosphere.

Even though subsequent stages (practical limit, three-stage total) must handle the full weight flow from previous stages, the setup is still more economical than steam. Water consumption, injected to control temperature, is the same as would be needed for makeup in cooling towers associated with condensers on a steam system.

▶**Boost Energy Level**—Energy level in the motive fluid has a major bearing on the performance of an ejector. Using plant air, this level is limited by the generally prevailing conditions of 100 psig. and 200 F.

However, if this air is used as the combustion air in a high-heat-release burner, its energy level reaches a new height that makes it a better motive fluid for ejectors.

In the Graham gas ejector, fuel oil or fuel gas is burned in a Thermal burner (see *Chem. Eng.*, Dec. 1952, p. 104; Feb. 1953, pp. 208-209; Feb. 1957, pp. 164-166) with 60-psig. air to produce gas at 3,500 F. Water injected into the hot gas stream lowers the temperature to 800 F. so that special materials of construction are not required.



LaBOUR Type SZ

This newest member of the LaBour pump family has been created to deliver traditional LaBour dependability and long service life combined with new installation and maintenance arrangements which may be important in certain situations.

The casing of the SZ is integral with inlet and outlet passages and is independently supported on the base plate. If desired, a complete new drive unit with impeller may be installed without disturbing the piping connections or the motor.

Type SZ is a single stage non-priming centrifugal able to handle large quantities of air or gases mixed with the liquid. It uses a fully open impeller, and there are no sealing rings or closely fitted pumping parts. This pump is available in various corrosion resistant materials to meet practically any requirement.

Your copy of bulletin D-3 with full particulars on the SZ is waiting for you. Ask for it—today.

LaBOUR

Equipment Developments This Month

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Total energy in the flowing gas remains the same because the drop in temperature is accompanied by an increase in the mass flow due to the added water vapor.

▶ **At the Inlet**—The mixture of combustion gas and water vapor flows through the ejector inlet nozzle at supersonic velocity. Load air or gas in the suction chamber is entrained by the motive stream and carried through the diffuser and out of the system.

In a typical Graham gas ejector, gas mass flowing through the inlet nozzle is contributed 54.4% by air, 4% by fuel and 41.6% by injected water. Every pound of this motive fluid entrains 0.67 lb. of load gas or air. In this fashion, a single stage can make 26 in. Hg vacuum.

The total energy existing in the motive stream at the inlet nozzle is contributed 3.5% by the compressed air and 96.5% by heat released during combustion of fuel in the burner.

▶ **How It's Controlled**—As already noted, temperature of the gas can be regulated by injecting water. Although the optimum level may be around 800 F., it can be dropped much lower without harming performance.

Suction pressure is controlled by throttling inlet air pressure. Temperature of the burner exhaust stream is sensed and used to control flow of fuel oil, which is measured with a turbine-type flowmeter. — **Graham Mfg. Co., Batavia, N. Y.** **182A**

Equipment Cost Indexes

	Dec. 1956	March 1957
Industry		
Avg. of all	218.3	222.2
Process Industries		
Cement mfg	208.6	213.1
Chemical	218.8	223.3
Clay products	202.6	207.0
Glass mfg	206.7	210.9
Paint mfg	210.5	214.8
Paper mfg	210.9	215.2
Petroleum ind	214.9	219.3
Rubber ind	217.6	222.1
Process ind. avg	216.2	220.7
Related Industries		
Elec. power equip	220.8	225.6
Mining, milling	220.2	224.7
Refrigerating	245.9	250.9
Steam power	206.1	210.3

Compiled quarterly by Marshall and Stevens, Inc. of Ill., Chicago, for 47 different industries. See Chem. Eng., Nov. 1947, pp. 124–6 for method of obtaining index numbers; March 1957, pp. 266–7 for annual averages since 1913.

Plastic-Lined Pumps

Supplement lined pipe, valves and fittings.

Introduction of saran-lined centrifugal pumps supplements saran-lined pipe, valves and fittings to make possible completely corrosion-resistant piping systems.

Pumps are fitted with mechanical rotary seals designed to eliminate high frictional heat failures and resultant leakage problems of packing glands. Seal-cooling systems use either process fluid or water.

Sizes are 1½ x 1 in. and 3 x 2 in. — **Saran Lined Pipe Co., 2415 Burdette Ave., Ferndale 20, Mich.** **184A**

Outlet Connection

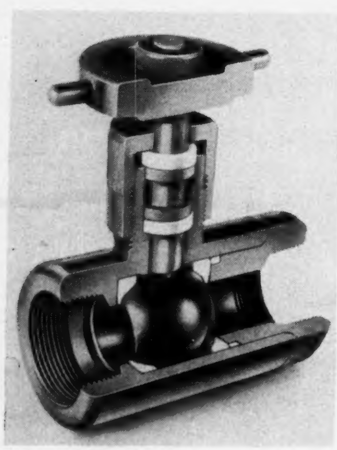
For branches out of pipelines, tanks, vessels.

Now in full production is the new Couplet line of easy-to-install branch outlet connections for pipelines, tanks and pressure vessels.

Designed as a universal out-

let connection, Couplets are used without modification on most applications. On applications to small-diameter pipe it is modified easily by contouring the welding end with an acetylene torch to mate with the curvature of the pipe diameter.

Available in sizes from $\frac{1}{4}$ through 2 in. with screw-end or socket-welding end connections, these Couplets are also available in 90-deg. elbows.—**H. K. Porter Co., Inc., P. O. Box 95, Roselle, N. J.** **184B**



Ball Valve

Constructed of PVC for corrosive service.

Now available is a Double-Seal-design ball valve constructed of PVC for handling corrosive and other difficult fluids. Sturdy construction permits use in many plastic or metal piping systems for either vacuum or pressure service. It is first all PVC valve offered with air operator.

Features of the new valve include full flow, $\frac{1}{4}$ turn shutoff, with thousands of leak-tight cycles and no maintenance. Valve seats replace easily.

Rated at 150 psi. at ambient temperature and 50 psi. at 130 F., the valve comes in sizes from $\frac{1}{2}$ to 2 in. Soon 3 and 4 in. sizes will be available in flange and weld ends. — **Jamesbury Corp., 62 Millbrook St., Worcester, Mass.** **186A**

Insert Flanges

Make possible piping changes without welding.

Through use of Speedline insert flanges, it is now possible to tie in new equipment and break into existing lines and headers without resorting to welding.

Pipe or Speedline stainless steel fittings can be expanded into the insert flanges to minimize down time and make strong leak-proof joints. Press fit between insert and flange assures that the pipe or fitting can be expanded into the ferrule permanently. — **Horace T. Potts Co., Erie Ave. & D St., Philadelphia 34, Pa.** **186B**

Sump Pump

Self contained unit driven by compressed air.

A new self-contained, air-operated portable sump pump can handle a wide range of jobs. It can remove sewage, sludge, chemicals, oil or water from sumps, wells, excavations, mines, quarries, ditches, trenches and cellars.

Pump body, impeller and strainer are bronze to resist corrosion and to insure spark-free operation. Thus, chemical solutions, inflammable and explosive liquids can be handled safely.

Pump requires no priming, is ready for instant use. It will pump from any pool over $1\frac{3}{8}$-in. deep.—**Schramm, Inc., 900 East Virginia Ave., West Chester, Pa.** **186C**

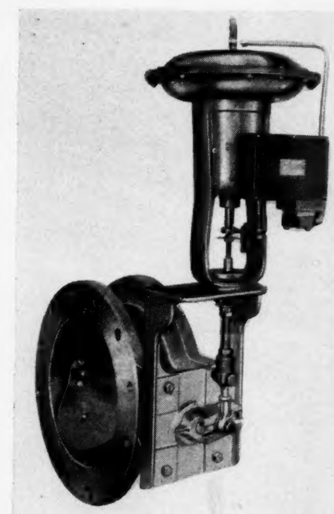
Steam-Traced Pipe

Has new cross section to match standard pipe.

Lower cost and higher efficiency of steam-traced piping now are reported possible with the new Unitrace design.

When introduced in 1953, Unitrace was oval in shape. Recently, Alcoa's engineers redesigned the one-piece, steam-traced piping so that the cross section matches standard pipe sizes. Immediate advantages are lower cost per foot and easier, faster installation. In use, the new design boosts the efficiency by increasing transfer of heat internally and cutting heat-loss of external radiation.

Unitrace is available in nominal sizes of $1\frac{1}{2}$-, 2-, 3- and 4-in. —**Aluminum Co. of America, 790 Alcoa Bldg., Pittsburgh 19, Pa.** **186D**



Valve Operator

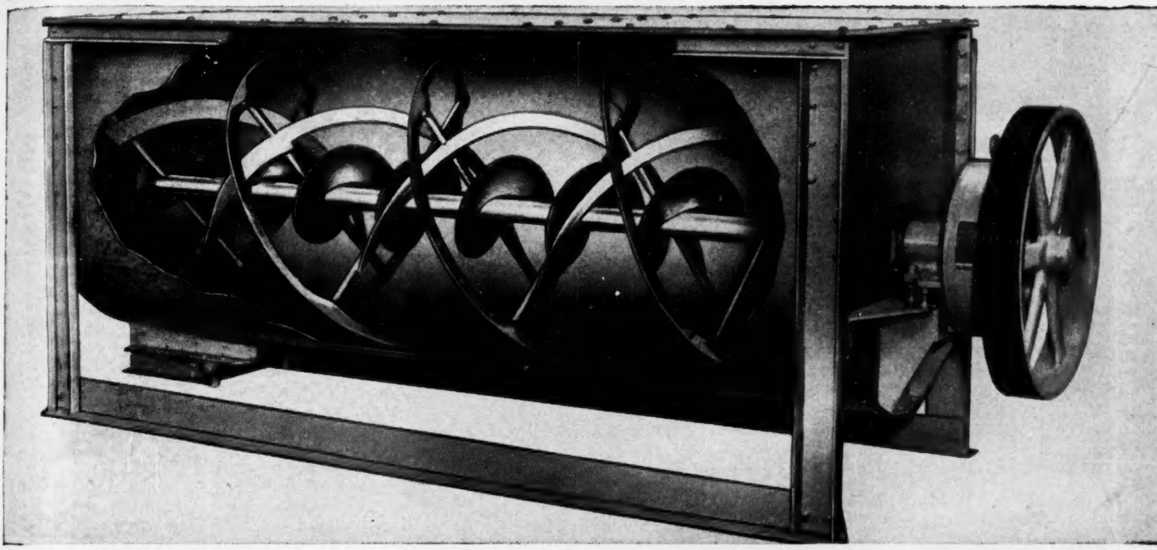
Provides maximum range of valve adjustment.

A new standard bracket and linkage arrangement for butterfly valves greatly simplifies their hookup with automatic control operators. At the same time, it offers distinctive and important advantages in operation, adjustment and maintenance. Less power is needed in close control applications.

Design provides an almost friction-free connection between the operator stem and the valve shaft with no sloppy fits. There is no chatter nor hunting, even when throttling the valve disk under the most critical control conditions.

Bracket and linkage are standard for butterfly valves up to 48 in. pipe size, in accordance with required torque.— **W. S. Rockwell Co., 200 Eliot St., Fairfield, Conn.** **186E**

NEW PRODUCT NEWS



PRECISION MIXING WITH NEW TRIPLE ACTION MIXER

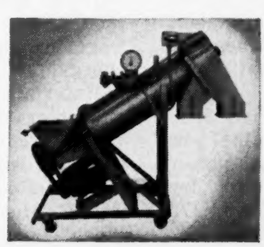
Strong-Scott Mixer Offers Uniform Blending and Mixing in 2 to 7 Minutes with 99.9% Thorough Distribution of Minor Additives.

Now, for the first time, a batch mixer with exclusive "Triple Action" mixing. The blending, folding and mixing action created by this unique triple ribbon and spiral assembly exposes each particle in the mixture to over 10,000 separate mixing actions per minute. The center spiral breaks and tumbles the core of the mix and moves the material to the outer 2 ribbons which convey the ingredients in opposite directions, subjecting each particle to thousands of mixing actions per minute. This produces a well balanced, uniformly mixed product of the highest efficiency known.

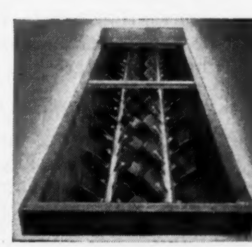
EXCLUSIVE FEATURE — Nylon seals between the tub and shaft, with outboard bearings. This permits cleaning in a matter of seconds . . . is sanitary, long wearing and dustproof. There is no hold up of product from one batch to the next.

The versatile design of the Triple Action Mixer permits feeding from any location at the top with single or multiple discharges to suit individual requirements. Hinged, drop-door bottoms for easy cleanout. Constructed of steel, stainless steel or commercial alloys.

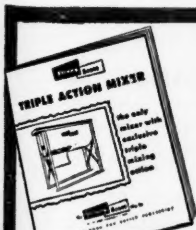
Strong-Scott maintains a complete Customer Service Laboratory with a full line of standard equipment for your convenience, with no obligation to you. Consult Strong-Scott for additional details.



PORTA-BLEND—A portable dry mix and liquid blender capable of quality results at high capacity.



TWIN ROTOR MIXERS—Accurate blending of liquids and dry mix at high or slow speed.



WRITE FOR FREE COLOR BULLETIN

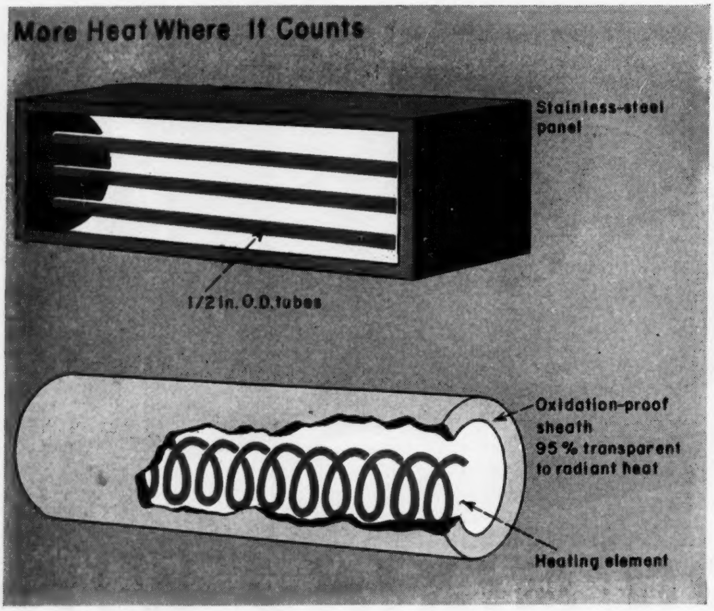
For complete information on the equipment shown above, write to The Strong-Scott Mfg. Co.

The Strong Scott Mfg. Co.

DEPT. CE-06

Equipment Designed for Better Processing

451 TAFT STREET, MINNEAPOLIS 13, MINNESOTA



Heater Emits Wider Spectrum

Wide-frequency radiation from new infrared heater converts more completely to heat at receiving surface. Users report it cuts power usage and processing time.

In heating performance, the new Velotron radiant heater is claimed to surpass either conventional infrared filament lamps or metallic-sheathed heaters. Here is what some users report:

- Production rate rises 25% in textile-drying operation.
- Unit uses 40% less power than previous lamps to dry latex and plastic cements in 1/6 the space.
- Lacquer on glass dries 25% faster using 1/5 the previous heater rating in 1/12 the space.
- Food-processing oven uses 45% less power.

▶**More Heat Where Needed**—When radiant heat rays hit a given surface, some of the rays are absorbed by the surface and others are reflected. Only those rays which are absorbed actually produce heat. How many of the incident rays are absorbed depends upon the color, chemical composition and physical properties of the surface being heated; and the wave length(s) of the radiant energy.

Materials of various types and colors respond to a range of different frequencies that extends from 2 to 10 microns in the effective infrared heat region. Heat rays that have a given frequency within this range may dry or cure one type of material rapidly, yet fail completely on a different type. That's why Velotron feels that a radiant heat source should produce heat rays over a wide frequency band in the radiant-heat region.

▶**Heat Source**—The Velotron radiant element consists of a specially coated central resistor element made of an exclusive alloy developed for radiant heating use. Surrounding the resistance element is a nonmetallic silicon-compound-aggregate sheath which is 90% transparent to radiant energy. The reasons why the Velotron element produces a wide band of frequencies are related to the characteristics of this sheath.

Frequency of the initial radiation from the resistor element inside the sheath is entirely a function of the temperature; at 2,000 F., for instance, the energy will radiate at one frequency. As this energy passes through the silicon sheath some of the rays convert to heat and then back to radiant energy again.

During this conversion step, the frequency changes. Energy re-radiating from near the interior of the sheath will differ in frequency from that re-radiating near the exterior of the sheath. Net result is a spread of frequencies from 2 to 10 microns.

Little of the energy produced is lost in heating the sheath itself. Due to the transparency of the sheath, there is no need to heat it physically by conduction to produce radiation. Temperature drops from 2,000 F. at the filament to approximately 900 F. at the sheath surface.

Selection of the heating element, sheath thickness and the various spacings involved have been determined experimentally so that the proper harmonics will be generated throughout the 2-10 micron range.

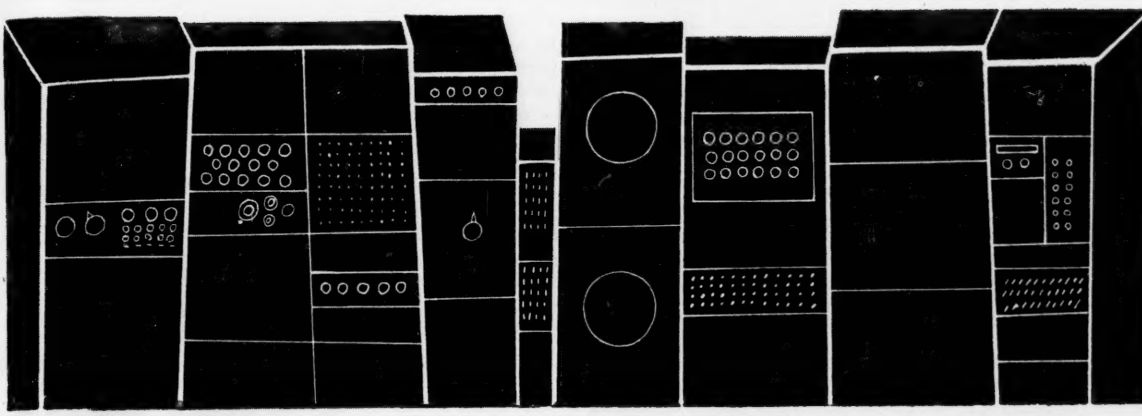
▶**Built to Take It**—Average service life of the heating element is more than 5,000 hr. It can be replaced easily, reusing the original sheath.

The sheath tube is electrically neutral and can withstand sudden thermal shock. Even cold water poured on the hot tube will not crack it. And since 90% of the rays emitted are heat rays rather than light rays, protection of personnel against harmful glare is unnecessary.

▶**Complete Assemblies** — Velotron heaters are sold completely assembled, wired for either single or 3-phase operation, 115-550 v.

Type SMFR consists of a single 1-in. O.D. Velotron tube

simple as a desk calculator...



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combines advantages of both . . . and solves the problems "in-between," at low cost and with big savings in technical man-hours. Pinboard programming – an exclusive feature of the E101 digital computer – can be mastered in six hours; familiar notations, no coding. That's why more E101's are *at work* than all other comparable computers combined. Immediate delivery; instant serviceability. As a test: send us one of *your* problems. We'll program it, send your solution and proof of how we can serve. For demonstration, or descriptive booklet, write:

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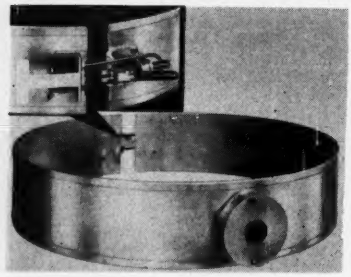
mounted in an 8-in. semi-circular stainless-steel reflector. Type PMFR is a multiple-tube panel with ½-in. O.D. tubes. Type TF is a tubular furnace which has a 1-in. tube centered within a circular stainless-steel housing, flanged at both ends. **—Velotron, Inc., 1186 Broadway, New York 1, N. Y. 188A**



Drum Heater

Improves conduction of heat through drum wall.

Better heating for 55-gal. drums is claimed for the new RH-1 Acrawatt drum heater. Unit is designed to heat 22¼-in. dia. drums containing materials such as plastic resins, molasses, fats, adhesives and non-volatile chemicals.

Heater features a new quick-action toggle clamp for applying the heater to drums. Built-in three-setting switch gives choice of 100%, 50% or 25% of maximum heat output. Actual heat input to the drum, without added thermal insulation, is reported to be 65 to 85% of the total generated wattage which is 3,000 w. at the 100% setting.**—Acra Electric Corp., 9909 Pacific Ave., Franklin Park, Ill. 190A**

Air Heater

Operates more efficiently, uses less fan power.

Offered as the culmination of years of research, the new Counterflo series air heaters increases heating efficiency by providing more hot air with less fan horsepower.

Based on a 75-deg.-F. temperature rise, fan requirements range from ½ to 7½ hp. for heater sizes from 250,000 to 2 million Btu/hr. output capacity. Air-heat ratios range from 11,000 to 16,000 cfm./1 million Btu./hr. output. Regardless of size, the heaters operate at a minimum efficiency of 80%.

There are two basic separate components in the new Counterflo unit. The furnace section includes a Pyro-Jet induced draft burner, stainless-steel combustion chamber with true airfoil flow passages, secondary heat transfer tubes of aluminized steel and electronic flame-failure protection. The second section contains forward-curved, low-speed, double-inlet fans.

The two-part design permits wide flexibility in matching fan requirements with heater outputs. Also, it permits use of low-cost standard furnace assemblies for special ventilation installations, oven heating and process drying and integration with air conditioning systems which usually require large centrifugal fans.**—Dravo Corp., Neville Island, Pittsburgh 25, Pa. 190B**

Steam Trap

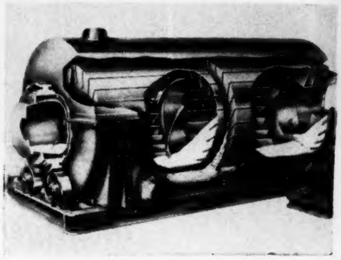
New type discharges steam-hot condensate.

The Monovalve float-thermostatic steam trap, built to discharge condensate at steam temperature, uses only one valve to vent air, discharge water and check back flow.

In cold state, the valve is kept open by line pressure or gravity for high-capacity air venting. When steam enters the trap body, the bimetallic element closes the valve tight. For cool condensate, the valve operates as in standard bimetallic Velan steam traps.

When steam-hot condensate enters the trap the bimetallic element doesn't know the difference between it and steam, so it remains closed. However, the accumulating condensate raises the float which overcomes closing pressure from the bimetallic element and opens the valve to full-open position for high-capacity discharge.**—Velan Valve Corp., 37 South River St., Plattsburg, N. Y. 190C**

For More Information . . . about any item in this department, circle its code number on the **Reader Service** postcard inside the back cover



Rotary-Louvre Cooler

Employs water as the cooling medium.

An entirely new cooler for crystalline or powdered solids has hollow, water-cooled louvres to move and cool the solids.

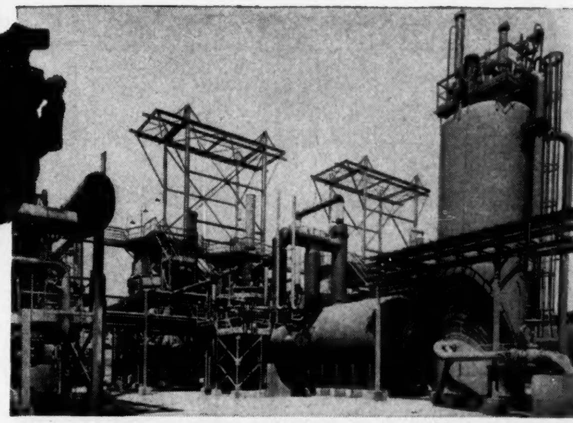
Unit illustrated above is a two-stage unit. As the drums revolve slowly, the hot solids enter through an opening on the axis. Action of the louvres moves the material through the cooler and gently circulates the individual particles from the bottom to the top of the bed. The particles give up heat to the cool surfaces of the louvres.

Drums dip into a water bath so that the hollow louvres pick up water as the drum revolves. The water flushes along the louvres, flowing counter to the material inside the drum.

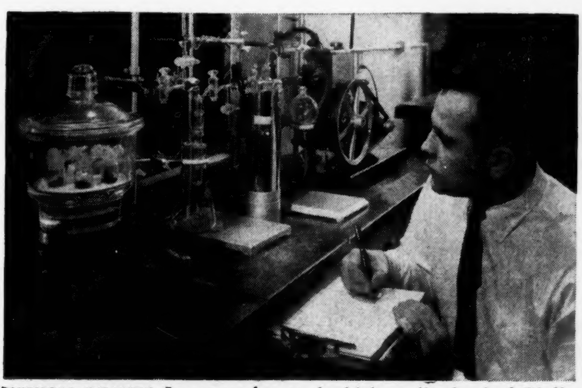
Cooler is manufactured in one, two or three stages and in a range of diameters and lengths. Parts that contact product are normally mild steel, stainless steel or aluminum while the water bath and its enclosures are of galvanized mild steel.**—Dunford & Elliott Process Engineering Ltd., Linford St., London S. W. 8, England. 190D**

Performance exceeds claims for G-29 steam-hydrocarbon reforming catalyst

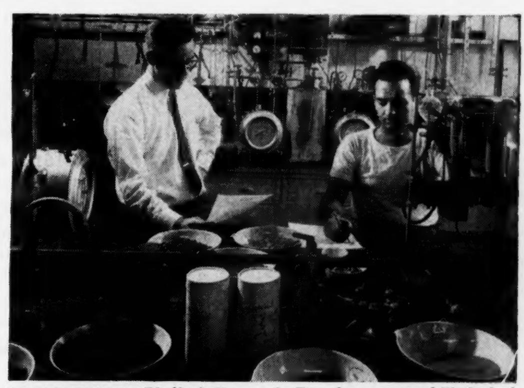
THIS IS G-29. A nickel base catalyst containing approximately 27% nickel. For reforming of hydrocarbons at temperatures of 1100°F to 1850°F in production of ammonia and methanol synthesis gases, hydrogen, OXO synthesis gases, controlled atmospheres, carrier or utility send-out gases.



USED IN ADAMS TERMINAL AMMONIA PLANT of Phillips Chemical Company. Girdler catalyst specialists studied the production of ammonia synthesis gas in secondary reformers. Cooperating with Girdler, the Phillips Chemical Company ran pilot plant tests and selected G-29 catalysts for this application. Results: Catalyst performance exceeds Girdler claims. *Methane in reformer effluent is less than 0.1 mol per-cent at normal operation.*



PHYSICAL QUALITY. Important key to the high quality level of Girdler catalysts is the extensive series of physical measurements continually being applied to them . . . to show such properties as surface area, pore volume, particle size, shape and density, crystal structure. Test shown is for pore volume.



YOUR PROBLEM? Girdler's Research, Development and Technical Service groups combine sound scientific theory and extensive commercial experience in the solution of catalyst problems. This know-how and Girdler's continuing program of product improvement, high quality control standards, and a keen appreciation of customers' catalyst problems can help you.

Write for free bulletin No. GC 1256, cataloging Girdler's full line of catalysts.

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The GIRDLER Company

A DIVISION OF NATIONAL CYLINDER GAS COMPANY
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Girdler Manufactures Catalysts for: Hydrogenation • Synthesis Gases and Hydrogen Generation • Desulfurization • New Catalytic Processes

Sonar Caliper

Measures size and shape of large underground cavities.

A new electric-line tool, called a sonar caliper, has been developed to measure the size and shape of underground cavities by converting reflected sound waves into distance. A survey made with the caliper consists of a series of horizontal cross-sections of the underground cavity.

The tool is 50-in. long with a $3\frac{1}{2}$-in. diameter. Its size permits it to be run through 4-in. ID pipe, suspended on a single conductor wire line. It can be used in such applications as measuring brine well cavities and determining the capacity of LPG storage reservoirs.

The caliper works on the pulse-echo idea, timing the rate of sound travel through a fluid medium. The outside circumference of the cavity is shown on a Polaroid photo-recording unit. The sonic sending and receiving devices in the tool continuously rotate, as the data is automatically and permanently recorded.—**Dowell Inc., Box 536, Tulsa, Okla. 192A**

Liquid-Level Switch

Radioactive probe sensitive to missile fuel level.

A unique liquid level switch, utilizing a beta source in its sensing element, is now available for the control of critically important fuel levels in supersonic aircraft and missiles. It is said to be smaller, lighter and more durable than any similar device.

The switch consists of a pencil-sized sensing probe containing a beta source and a beta detector which is mounted inside the fuel container. The relay within the switch is actuated by radiation variations caused by liquid level changes in a small cavity between the beta source and detector tube.

Tests show that the device performs reliably and accurately under extremes of temperature, vibration and shock. Since there is no exposed electrical potential, explosion and fire hazards are minimized.—**Aeronautical Div., Robertshaw-Fulton Controls Co., Anaheim, Calif. 192B**

Liquid-Level Sensor

Controls within 1/32 in. using ultrasonics.

Stable sensing of liquid level without interference from foam or clinging droplets is reported for a simplified sensor that uses an ultrasonic probe. Unit can be used on virtually all liquids at temperatures from −270 to +220 F.

Ultrasonic sensor responds instantaneously and is entirely safe when gaging hazardous, explosive liquids. No temperature correction circuits are required nor are any adjustments needed to compensate for any other variables.

Gage operates on the principle that an ultrasonic transducer in contact with a liquid presents a terminal impedance appreciably different than obtained when it is purely "air-loaded." A transitorized electronic control unit outside the tank energizes a relay when the level passes the sensitive face of the transducer.

Complete unit, including transducer and control, weighs under 12 oz. and uses only 20 w. of power.—**Acoustica Associates, Inc., Glenwood Landing, L. I., N. Y. 192C**

Valve Controller

All-electric type mounts on rotary valve stem.

Remote or automatic operation of valves with proportional or on-off control is provided by the Valvetrol all-electric rotary valve controller. Device is designed to mount on the valves sold by all leading manufacturers.

The Valvetrol is a self-contained gear motor with hollow output shaft that receives the valve stem. Stem diameters from $\frac{1}{4}$ to 1 in. can be accommodated.

Valvetrol incorporates a built-in potentiometer which may provide remote indication of valve position. Or it may be used as part of a balanced bridge circuit.

A wide variety of gear ratios is available to produce the desired torques and operating speeds. Selective gear ratios to the potentiometer adapt the Valvetrol to valves having anywhere from $\frac{1}{8}$ to 40 turns to full open.—**The Jordan Co., Inc., 3235 West Hampton Ave., Milwaukee 9, Wis. 192D**

Analysis Cell

High-temperature thermal type extends range.

Effective operating range of chromatographic analyses now can be extended appreciably through use of a new high-temperature thermal conductivity cell. Exceptional stability and sensitivity at high temperature is achieved for the first time by use of flake thermistors as sensing elements.

Operating range for the model 75 cell extends from 30 to 325 C., and will accommodate liquids with boiling points up to 425 C. This is virtually at the upper operating limit of chromatography because organic molecules begin to break down beyond this point.

The cell may be incorporated into any existing chromatographic apparatus.—**Barnes Engineering Co., Stamford, Conn. 192E**

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...and save valuable shelf space, too!

The broad flat surface of every "F" style can acts just like a poster for your product. The handsome lithography of Continental's master craftsmen quickly identifies your product in the eyes of busy shoppers... makes your product more attractive, easier to see, easier to sell. And because of the space-saving rectangular shape, "F" style cans let grocers stock *more* of your product per shelf foot.

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Plastic Welder

Can be used satisfactorily by maintenance help.

Performance of the new Seelye model P plastic welder covers the welding requirements of all thermoplastic materials from thin polyethylene sheet to the heaviest PVC in current use. Yet, operation is so simple that even maintenance personnel without special training can master it with minimum practice merely by following the simple operating instructions. This permits companies with special, corrosion-proof plastic pipe and duct installations to perform maintenance quickly and economically without having to call in outside help.

Welder normally is equipped with 320-w. heating element, but other ratings can be installed where needed. Complete welder weighs only 14 oz.—**Seelye Craftsmen, 984 Central Ave., Minneapolis, Minn.** **194A**

Lined Steel Drums

Introduce centrifugal spray lining for steel containers.

Linings for the interior of steel shipping drums can now be applied by centrifugal force. Fully automatic mechanism is capable of achieving an unusually high degree of film thickness uniformity throughout the entire container.

High quality, consistency and high production rates for lined containers are now realities. Centrifugally spraying inner-coat drum linings now makes it possible to use lining materials with a substantially lower solvent content. No air is entrained in the lining material when it is applied by this method.

The new spraying technique plus new curing oven equipment result in improved containers for products that are chemically active in the presence of steel.—**Rheem Manufacturing Co., 7600 South Kedzie Ave., Chicago 29, Ill.** **194B**

Paint Mixer

Shortens mixing time, makes smooth mix.

Difficulty in mixing protective coatings of all types is overcome through use of the Jiffy mixer. Fitting into practically any standard electric or pneumatic portable power tool, this mixer shortens mixing time and produces uniform smooth mixtures.

One big advantage of this device is freedom from splashing and danger of cutting into the container walls. No air can be sucked into the mix. Yet, solids can be thoroughly freed from bottom and sides of the container as the operator moves the mixer about through the container.—**Jiffy Mixer Co., Inc., 515 Market St., San Francisco 5, Calif.** **194C**

Leak Indicator

Wrap-around tape discolors with acid.

C. S. Moore, Safety Director at Squibb Div. of Olin Mathieson Chemical Corp., examines one of the first installations of a new plastic tape that indicates when acid or caustic lines are leaking. The taped pipe above Mr. Moore's hand has been triggered with acid so that you can see how it discolors.

Tape was developed at Mr. Moore's request as a method that would increase protection of workers in areas where acid lines are strung overhead. In addition, it prevents damage to equipment in such areas. In some cases, it is used to cover plastic piping systems which might split under vibration.

Tape is made of fiber glass covered with vinyl resin and coated with a patented indicator. A thin protective coating prevents triggering of the indicator by fumes or climatic conditions.

Wrapped around pipelines, this tape will indicate by discoloration anywhere a leak or weep develops. Acid lines are covered with a red-colored indicator that turns yellow when triggered by leaking acid. A white-colored tape that turns purple is used for caustic lines.

Tape is available in widths from 1 to 38 in. and in lengths up to 300 ft. Both indicating and non-indicating valve and flange covers are also available for use with the tape to protect personnel.—**Neirad Industries, Inc., P. O. Box 865, Darien, Conn.** **194D**

Bellows Seals

Seal shafts at extreme temperature.

A new series of metal-bellows mechanical shaft seals operates efficiently at temperatures above +700 F. and below −100 F. They are recommended for use where acids, solvents or other chemical agents will destroy the organic components of other types of seals.

Each seal is tailored to meet specific requirements and is provided to fit any shaft size, complete with mating faces. Spring rate is controlled to allow greater axial movement with hydraulic pressures balanced exactly as required. Seals are supplied in brass, bronze, beryllium copper, Monel or stainless steel with bellows joints of soft solder, silver solder, heliarc or resistance welded.—**Cartriseal Corp., 3515 West Touhy Ave., Lincolnwood, Ill. 196A**

Lubrication Fitting

Relief type simplifies and speeds greasing.

Tests have shown that the new Keystone RT fitting can cut lubricating time for anti-friction bearings 80% or more. It is available for use on bearing housings now equipped with conventional relief plugs.

Fitting has a patented flip-open cap which responds to the touch of a finger. Because it is attached to the fitting, the cap cannot be lost. The body of the fitting is flared internally to allow free discharge of excess grease.—**Keystone Lubricating Co., 3100 North 21st St., Philadelphia 32, Pa. 196B**

Wrench Booster

Boosts wrench turning force four times.

Used with standard sockets and wrenches, the model TD wrench booster provides a four to one mechanical advantage for loosening and tightening heavy threaded parts easily and safely. By increasing a man's strength four times, the tool eliminates personal hazards and reduces equipment damage from force applied poorly.

All standard torque wrenches can be used with the TD booster. To get the applied torque output, just multiply the torque wrench reading by four. High-tensile steel bolts can be tightened to exact high-torque values by steady pressure without inaccurate and dangerous impact methods.

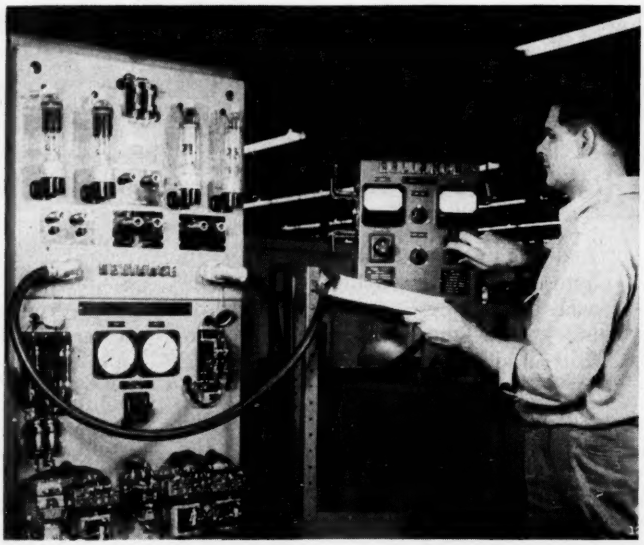
Heart of the booster is a set of planetary gears built into a simple concentric tool head. It can be dismantled completely within seconds for occasional cleaning or lubrication.—**X-4 Corp., Acton, Mass. 196C**

Engine-Compressors

New refrigeration compressors for continuous operation.

Self-powered compressors, available in three sizes with capacities ranging from one to five tons, are being offered where adequate electricity is lacking.

Intended primarily for mobile use or for cooling any enclosure needing a self-powered system, the units consist of high-speed refrigeration compressors directly connected to short-stroke, 4-cycle, air-cooled engines. Compressors are mounted directly to engine.—**D. W. Onan & Sons, Inc., Minneapolis 14, Minn. 196D**



Dual Design Keeps Motor Control on Line

To provide utmost performance continuity, Reliance has developed this dual-circuit, variable-speed, electronic regulator for mill drives in industries such as paper, rubber, glass and nonferrous metals. Normally, the circuits operate in parallel sharing the load. In case of tube failure in one of the circuits, the operable circuit instantaneously picks up and carries the full load. Electrician is checking various components of regulator with special test fixture during scheduled maintenance of electrical equipment. —Reliance Electric & Engineering Co., 24701 Euclid Ave., Cleveland 17, Ohio. 196E

Partial List of Material Processed with Allis-Chalmers Heat Transfer Equipment

- Limestone
- Lime
- Dolomite
- Magnesia
- Alumina
- Bauxite
- Manganese Oxide
- Iron Ore
- Phosphates
- Refractories
- Foundry Sand
- Petroleum Sand
- Petroleum Coke
- Fuller's Earth
- Nickel Ores
- Copper

How Allis-Chalmers Can Help You

Cut Heat Transfer Costs

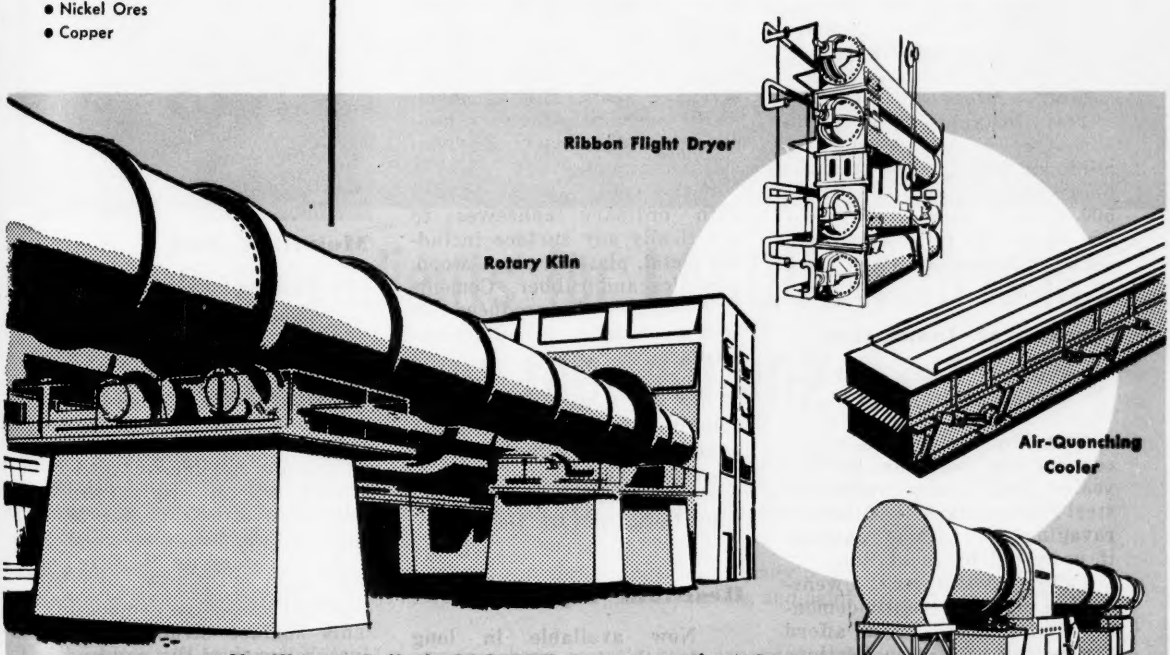
Obtaining increased production, lower processing costs and improved product quality is more than a matter of installing the best heat transfer equipment. Maximum utilization of that equipment also calls for an *efficient flow design.* You get *both* from Allis-Chalmers.

A-C Engineers Work With Your Staff or Consulting Engineers

Allis-Chalmers engineers concern themselves with overall operation . . . the evaluation of variables . . . plant design . . . the integration of interdependent equipment into a complete process.

Pre-recommendation research, testing and, of course, expert installation and localized field service are also available from Allis-Chalmers — the world's leading manufacturer of rotary kilns, coolers and associated equipment.

Equally important is the fact that Allis-Chalmers interest in your problems is continuous. Laboratory services, periodic equipment check-up and parts service are yours for the life of the equipment — and a long life it is, too.



You'll want Bulletin 25C6177. See your nearby A-C representative or write Allis-Chalmers, Industrial Equipment Division, Milwaukee 1, Wisconsin.

ALLIS-CHALMERS

A-5325

Gasketing Material

More flexible and durable, easier to use.

A new line of asbestos-fiber gasketing materials is unique in several ways. Sharp bending will not cause them to pipe or crack. Their unusual compressibility provides perfect sealing under lower bolting pressures than are required for hard compressed asbestos sheets.

Secret behind these properties is refining operation which removes all lumps and bunches from fibers prior to forming into sheets. The fibers then are coated uniformly with rubber binder by a patented beater-saturation process.

Test installations are reported to seal perfectly with minimum bolt torque loss where flange temperatures are up to 500 F. and internal pressures are up to 500 psi.—**Armstrong Cork Co., Lancaster, Pa.** **198A**

Structural Insulation

Prevents building collapse in case of fire.

Quite by accident, a major refinery fire two years ago revealed that heavy structural steel framework will withstand ravaging fire without damage, if protected by insulation.

Following this lead, Owens-Illinois officials recently demonstrated how Kaylo-20 can afford this type of protection. Sections of heavy, standard I-beams were encased in Kaylo-20 insulation and subjected to the flames of an oil fire for three hours. The amount of heat that penetrated the insulation was measured with thermocouples located in holes drilled in the beams.

External temperatures around the beams registered 1,980 F. Within the Kaylo covering, top temperature was 660 F., far short of the level where steel properties would be affected.—**Owens Illinois, Toledo, Ohio.** **198B**

Teflon Tape

New glass-reinforced variety of cementable tape.

Cementable Teflon tape is available for the first time in glass reinforced form. Compared to the unsupported variety, it has greater abrasive resistance, higher tensile strength, lower cold flow, improved dimensional stability and generally superior mechanical properties.

Continental-Diamond Fibre Corp. is offering a complete new line of both cementable, glass-supported and unsupported Teflon tapes. Corrosion resistance and non-sticking qualities of these tapes are of special value in the chemical process industry which utilizes them in scrapers, seals, and as chemically inert liners for vats, hoppers and other types of chemical containers.

Both types can be bonded with ordinary adhesives to practically any surface including metal, plastics, glass, wood, ceramics and rubber. Cementable surface is produced by treatment with a sodium-ammonia mixture.

Produced in widths from ¼ to 12 in. and in thicknesses from 0.002 to 0.06 in., the tapes are available with either one or both surfaces treated for adhesion. — **Continental-Diamond Fibre Corp., Newark, Del.** **198C**

Resistant Pipe

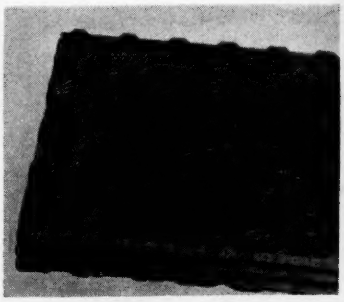
Now available in long lengths for process.

Two corrosion-resistant stainless steels, Carpenter Alloys B and C are now available for the first time in full-finished, long lengths of tubing and pipe. Mill lengths up to 20½ ft. are now supplied for use anywhere that extra long lengths are required for process lines, heating coils and similar uses.

Alloy B is a nickel-molybdenum-iron alloy with unusually high resistance to HCl in all concentrations and at all temperatures. It also has strong resistance to boiling sulfuric acid, phosphoric acid and wet hydrogen gas.

Alloy C is a nickel-molybdenum-chromium-iron alloy with excellent resistance to aqueous solutions of halogen salts, nitric acid and acid solutions of ferric and cupric salts.

All of this full-finished tubing meets the high quality requirements for heat exchanger applications. Sizes available include ⅝ to 4½ in. O.D. in tubing and ¼ to 4 in. in pipe.—**Carpenter Steel Co., Alloy Tube Div., Union, N. J.** **198D**



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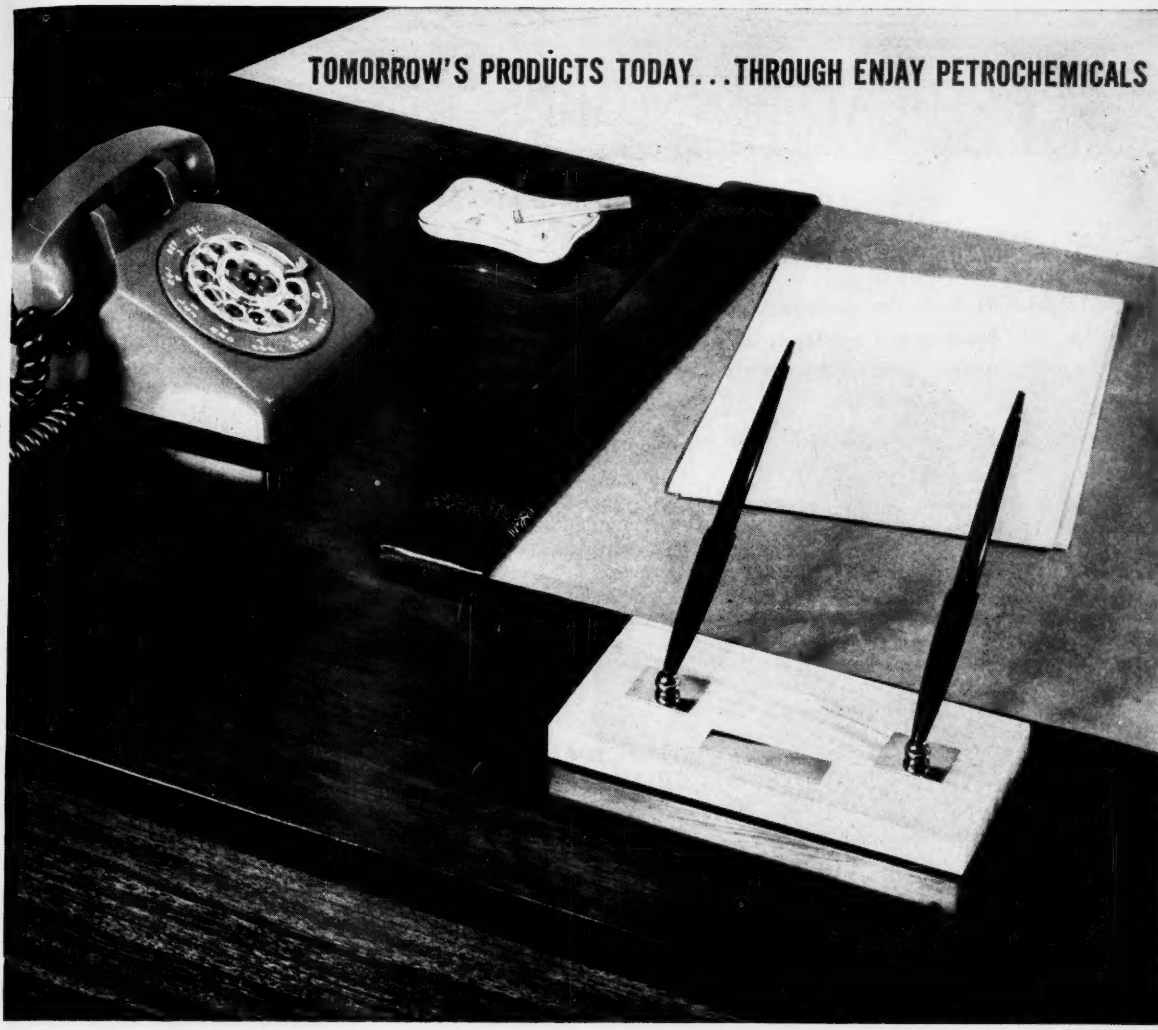

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DEVELOPMENTS . . .

CHEMICAL ECONOMICS EDITED BY D. R. CANNON

Tonnage Minerals Take Tonnage Chemicals

1.9 BILLION lb./yr. for nonferrous mineral processing in 11 Western States to turn out nearly all our copper, molybdenum, manganese, uranium, boron and tungsten; and more than half our lead and zinc.

1.3 BILLION lb./yr.—worth nearly $20 million—for processing bauxite to alumina.

10 MILLION lb./yr. (or more) of each of a dozen heavy chemicals like sulfuric acid and lime.

750 MILLION lb./yr. of nearly 250 different flotation chemicals.

For Chemical Producers . . .

Ore Processing Means Business

Raymond E. Byler, Arthur D. Little, Inc.*

Nonferrous mineral processing operations in the 11 Western States† consume some 1.9 billion lb. of chemicals per year, treating about 150 million tons of ores and minerals. Total value of these chemicals at present prices approximates $40-45 million. (See p. 202.)

If you add in the chemicals consumed in the biggest nonferrous mineral processing job outside the western territory — alumina production — you'll have a total of 3.2 billion lb. valued at $60-65 million.

A wide variety of chemicals is involved, but only those more commonly used have been selected for this brief discussion. And we are directing our attention to only the mineral processing which depends primarily on chemicals. This excludes sand, gravel, limestone, salt, clay, cement, fossil fuels and similar nonmetallics processed by physical or thermal means.

▶**How About National Totals?** —These figures give a pretty good line on the national picture, too, if you consider the qualifications we stated (nonferrous, etc.) and the fact that these same 11 Western States account for the lion's share of most of our metal production. They produce 93% of our copper, all of our boron and molybdenum, 97% of our manganese, 83% of our tungsten, 96% of our uranium.

Some exceptions: 53% of the lead, 54% of the zinc, 6% of the lithium, none of the alumina. Of course we can assume total consumption of chemicals for processing ores and minerals of these metals is roughly tied to total national metal production. But before you try to project figures for lead, zinc and lithium, some differences should be noted between chemical requirements of western ores and ores processed in other states.

▶**West Vs. the Rest**—Zinc-lead ores of the central states, for example, do not contain copper and can be concentrated by flotation without depressants such as cyanide and zinc sulfate. Also, these ores are upgraded by heavy media separation or jigging before flotation.

Lithium ores are concentrated in the Southeast by soap flotation using cationic collectors and a frother to remove gangue or waste minerals, while depressing spodumene with starch. Hydrofluoric or sulfuric acid is sometimes required as a cleanser. In the West, however, lithium is obtained from natural brines by partial evaporation, and then separation of dilithium sodium phosphate crystals from burkeite by soap flotation using kerosene.

Treatment of 7.3 million short tons of bauxite in 1955 involved 385,000 tons of soda ash, 264,500 tons of lime and 22,500 tons of starch—a total of 1.3 billion lb. of chemicals valued at about $20 million.

Consumption of fluorides, lime, and soda ash in electrolytic reduction of alumina to aluminum has not been included in the totals shown.

▶**Mineral Concentration** — Of the mineral concentration methods, flotation is by far the most important and widely used, and is a major chemical consumer.

Owing to large differences in surfaces of minerals as taken from the earth, and in chemical and physical reactions required to alter surface areas to induce or inhibit flotation, a wide variety of chemicals—some 200-250—is used in processing by flotation. They may be divided into three principal types: frothers, collectors or promoters, and modifiers. (See use breakdown, p. 202.)

Suitable frothing agents are generally organic substances which do not ionize to any extent in water, consist of molecules having both polar and nonpolar groups. Their function is to produce a froth of the desired bubble size and stability. Examples are pine oils, cresylic acid, coal tar deriva-

*Meet your author on p. 368. This article is based on a talk Ray Byler gave last fall at the Chemical and Mining Inter-Industry Conference sponsored by the San Francisco Chamber of Commerce.

† Wash., Ore., Calif., Idaho, Nev., Ariz., N. M., Utah. Wyo., Mont. and Colo.

tives, and aliphatic alcohols.

▶ **Froth Does the Floating**—Two fundamental requirements for the froth flotation process: (1) To prepare the surface of the desired mineral so that it only will adhere to bubbles of air which are passed through the aqueous suspension of minerals; (2) to provide relatively stable air bubbles for minerals to adhere to and be buoyed to the surface of the pulp, for removal from rejected or nonfloated minerals and rock.

Frothers are used in very small amounts—from 0.05 to 0.2 lb. ton of ore treated.

▶ **Promoters Help, Too**—Flotation promoters or collector reagents condition the mineral surface so it will adhere to air bubbles and float. Like frothing agents, promoters must have both a polar and a nonpolar group. But unlike frothers the polar group of a promoter must become fixed to the mineral surface either by chemical reaction or by adsorption (polar part of a frother should have an affinity for water only).

Promoters may be anionic or cationic. The anionic type is most useful for metal sulfide minerals, although various fatty acid products and alcohols promote flotation of some nonsulfide and nonmetallic minerals. A cationic promoter is useful principally for flotation of quartz and some silicates.

A great many chemicals have found use as promoters: aromatic amines, various xanthates, organic hydrosulfides, dithiophosphates, fatty acids and soaps, and various oils.

They are used in varying amount, depending on the type and amount of mineral to be floated. In general, sulfide mineral ores may require as little as 0.01 to 0.02 lb./ton ore, while nonmetallic and oxide ores for, which fatty acid promoters are used, require larger amounts ranging from 0.50 to 2.50 lb., and more, per ton of ore.

▶ **Depress or Activate**—Modifiers enhance or inhibit response of minerals to promoters and frothers, and regulate alkalinity of the pulp. They are usually referred to as "depressants," "activators," and "regulators."

Chemicals in Ore Processing: Specialties and Workhorses*

	(Thousand pounds)
Mineral Acids	
Sulfuric	850,000
Hydrochloric	14,200
Others	180
Alkalis	
Caustic soda	33,000
Lime	1,080,000
Soda ash	868,000
Sodium bicarbonate	36,000
Magnesia	4,800
Ammonia and Compounds	48,400
Sulfur and Compounds	
Sulfur	899
Sodium sulfide	3,000
Sodium sulfite	552
Carbon disulfide	445
Sulfur dioxide (as such)	31,325
Chlorine and Compounds	
Chlorine	1,000
Sodium chloride	17,000
Calcium chloride	3,120
Sodium chlorate	170
Compressed Gases, thousand cu. ft.	
Acetylene	3,000
Hydrogen	28,026
Oxygen	18,100
Propane, carbon dioxide	2
Nitrogen	3
Inert	40
Lubricants (oils, greases)	15,300
Explosives	32,500
Flotation Agents	†145,000
Others	
Corrosion inhibitors	2,565
Dispersants	2,000
Potassium permanganate	135
Manganese dioxide	315
Antimony and arsenic oxides	4
Glue	20
Gum arabic	70
Alum	205
Wetting agents	4,975
Defoamers	140
Rust preventives, gal.	5,600
Timber preservatives, gal.	17,400

*for mineral processing in the 11 Western States, and for production of alumina in the Southeast.

†Plus 611 million lb. of chemicals listed under "Alkalis" and "Sulfur Compounds."

Depressants hold back some minerals while allowing the desired mineral to float.

Lime depresses pyrite, the iron sulfide mineral.

Sodium dichromate depresses galena, the lead sulfide mineral.

Alkaline cyanide and zinc sulfate depress sphalerite, the zinc sulfide mineral.

Glues and starch depress talc and micacious minerals.

Tannins depress calcite, allow fluorspar to float.

Sodium silicate depresses silicious gangue minerals.

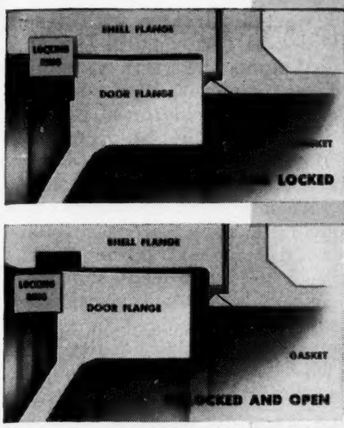
Caustic soda depresses stibnite, the antimony sulfide mineral.

Activating agents assist rather than inhibit flotation of the desired mineral. They may film or alter the mineral surface to enhance promoter effect. Copper sulfate, a good example, is universally used to activate sphalerite and pyrite. Hydrogen sulfide or sodium sulfide in proper amounts may be used to film carbonate minerals of lead and copper which otherwise do not respond well to promoters.

▶ **pH Makes the Difference**—Regulators adjust pH of ore pulp, disperse mineral slimes,

Profile of Flotation Agents

	(Thousand pounds)
Frothers	
Alcohols, ethers	4,570
Pine oils, other wood derivatives; cresylic acid, other coal tar derivatives	5,132
Collectors or Promoters	
Fatty acids and alcohols, amines, xanthates, hydrosulfides, dithiophosphates	40,586
Fuel oil, creosote	79,182
pH Regulators	
Lime	522,000
Soda ash	41,000
Caustic soda	13,400
Sodium sulfide	3,000
Sodium sulfite	500
Sulfur dioxide	31,325
Depressants	
Zinc sulfate, tannins, starches, alkaline cyanide, bleaches, lime, sodium chromate, glues, sodium silicate, caustic soda	11,345
Activators	
Copper sulfate, hydrogen sulfide, sodium sulfide	3,958
Others	
Flocculators, dispersants, emulsifiers	5,180



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or otherwise provide a favorable environment for flotation reactions. An alkaline circuit is required in flotation of most sulfide and nonmetallic minerals, although acid circuits are advantageous in some cases:

Lime is most common alkalinity regulator.

Soda ash is frequently used if a lower pH is important.

Sodium silicate and pyrophosphates disperse mineral slimes; lime and soda ash have some effect as dispersants.

The pH regulators are generally used in larger amounts —as much as 2 or 3 lb./ton of ore—than other reagents we have discussed.

▶ **Extractive Metallurgy** — Extractive metallurgy is another major category of mineral processing methods used in the West. Hydrometallurgy means processing in which chemical solvents extract metals from their minerals.

The chemical solvent is first applied to ore which has been ground or fractured sufficiently to expose desired mineral to the action of the solution. Large tonnages of oxidized copper ores and low-carbonate uranium ores are leached with sulfuric acid in the West.

On the alkaline side, sodium carbonate-bicarbonate solutions do the leaching in some uranium ore-processing plants in the West.

Chemical oxidizers promote dissolution of minerals. Most commonly used oxidizer is manganese dioxide, although potassium permanganate, sodium chlorate and others are sometimes used in minor amounts.

▶ **Collect from Extracts** — Second major step in hydrometallurgical operations is recovering metal that has been dissolved from ore and exists in the solution. For example, in the large western copper leaching operations, copper is precipitated from acid leach solution by metallic iron. Uranium and vanadium are precipitated from acid solutions with phosphate, or by neutralization and boiling off CO_2, and from carbonate leach solutions by caustic soda which neutralizes bicarbonate.

An interesting new commercial mineral processing method, L.P.F. (leach-precipitation-float), combines solubilizing copper with sulfuric acid, precipitating with metallic iron powder right in the ore pulp, and recovering the precipitate by froth flotation. This method has improved the economics of recovering copper from large low-grade, marginal deposits.

▶ **Enter Ion Exchange** — Another chemical procedure for recovering metals from solutions occurs in extractive metallurgy of uranium ores, and is now being used in production operations of at least five western mills. Ion exchange resins are contacted directly with leach liquor to remove uranium and vanadium, the resin is eluted with acidic sodium or ammonium chloride or nitrate solution, and the uranium precipitated from the eluate with ammonia or magnesium oxide.

An important development in uranium ore processing is liquid-liquid extraction of uranium from acid leach solutions. Aqueous insoluble phosphates, or amines dissolved in a nonmiscible organic (usually kerosene), extract uranium from the aqueous phase by complexing or by chelation.

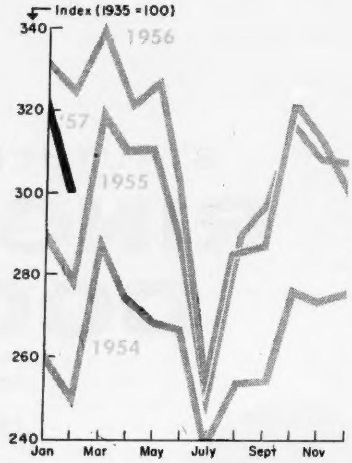
▶ **Chemical Refining**—Products of ore dressing and hydrometallurgical operations generally require further refining. Concentrates and precipitates of most common metals are customarily smelted. But many "new" metals so important to our modern technology—titanium, uranium, zirconium, thorium, niobium and tantalum —require chemical reduction.

Refining of oxides (except niobium and tantalum) generally means conversion to a volatile chloride or fluoride of the metal which is then purified and reduced by one of the lighter metals, magnesium or sodium.

In the West, imported zircon concentrates are chemically refined at Albany to hafnium-free zircon sponge by such a process. Likewise, titanium metal sponge is produced at Henderson by converting rutile concentrates to titanium tetrachloride in fluidized chlorinators, and then reducing with magnesium. Thorium is prepared by reduction of intermediate thorium tetrafluoride.

▶ **Upgrading Uranium** — Extensive use of chemical refining is made in the uranium industry to obtain reactor-grade materials from concentrates produced by hydrometallurgical ore processing. This usually proceeds by digesting the contrates with nitric acid to form uranyl nitrate which is recovered by liquid-liquid extraction using tributyl phosphate in kerosene, stripping the organic with water and evaporating, followed by thermo decomposition of high purity uranyl hy-

Chemical Consumption



Consumption by Industries

	Jan. (Final)	Feb. (Est.)
Coal products	12.1	10.7
Explosives	10.1	9.7
Fertilizer	73.4	71.9
Glass	25.8	24.7
Iron & steel	20.2	18.3
Leather	4.1	4.2
Paint & varnish	30.2	27.1
Petroleum refining	33.4	29.1
Plastics	23.6	26.0
Pulp & paper	38.6	34.8
Rayon	31.0	26.8
Rubber	7.7	6.9
Textiles	11.3	9.9
Total	322	300

drate to the trioxide. The latter is reduced with hydrogen gas to uranium dioxide and converted to uranium tetra or hexafluoride with hydrofluoric acid.

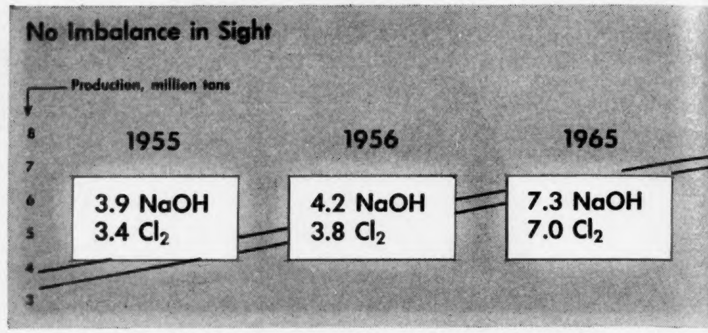
Another relatively new instance of chemical metallurgy is the processing of cobalt concentrates at Garfield. Hydrogen gas, with a catalyst, precipitates cobalt selectivity.

Chemical processing is used to upgrade flotation concentrates of tungsten and rare earths. In upgrading tungsten concentrates, digestion with hydrochloric acid removes carbonate and phosphate minerals, which float off with the scheelite raising the grade of concentrates to a trade specification of 60% tungsten oxide. Similarly, rare earth concentrates are upgraded by leaching flotation concentrate with hydrochloric acid.

▶ **Pyrometallurgy** — In pyrometallurgy substantial amounts of silica and limestone are used as fluxes in smelting metallic mineral concentrates. Use of chemical products, however, is limited, although chlorine, sulfur, caustic soda, and sodium chloride or nitrate figure in fire refining of smelter products.

Other thermal operations, such as calcining diatomaceous earth, use fairly large amounts of sodium carbonate or trona. Consumption is about 100 lb. per ton of finished material. A special instance of a thermal processing is the pelletizing of manganese flotation concentrates by adding sodium carbonate—about 3½ lb./ton.

▶ **Electrometallurgy** — Electrolytic reduction is used extensively in processing and refining of minerals and concentrates, and accounts for some chemical consumption. Addition agents like glue improve cathode effect in electrolytic cells, frothing agents reduce escape of acid mist by maintaining froth on the surface of cells, manganese dioxide is an oxidant in leaching. Ammonium chloride is a flux in the cathode casting furnace, and copper sulfate, arsenic oxide and other reagents purify leach solutions by removing cadmium, cobalt, antimony, arsenic, and other metals occurring with zinc.



Cl_2-NaOH: Harmony Ahead

Chlorine-caustic imbalance — oft-predicted, oft-deferred — is deferred again. Outlook for 1965: 7.0 million tons of chlorine, 7.3 million of caustic.

Robert Chien and Charles Gerlach, Wyandotte Chemicals Corp.*

The chlorine-caustic soda industry has been a subject of speculation in recent years, speculation that chlorine has matured and cannot maintain its high-stepping pace; that caustic soda demand cannot grow fast enough to keep up with a high-flying chlorine; that caustic growth is slowing; that imbalance is certain.

Well, the last couple of years have shown nothing to confirm these views. Both chlorine and caustic demand have been booming—and in cadence with each other. We see harmony ahead, too. Although adjustments may have to be made from time to time, we feel that 1965 will bring demands of 7 million tons of chlorine, 7.3 million tons of caustic soda.

▶ **Both Chemicals Strong**—Chlorine production rose to 3.4 million tons in 1955—17.8% over 1954—and tacked on another 11% gain to hit 3.8 million tons last year. Two mighty strong years even for a commodity with a growth rate of 10-11% since World War II.

As for caustic soda, it hit its average annual growth rate of 7-8% on the nose in 1956, moving to 4.2 million tons—and showing no firm signs of easing.

Admittedly, though, unless chlorine demand slackens or caustic can step up its pace, the industry faces a complicated adjustment problem.

▶ **Keeping a Balance**—Much has been written on how to achieve a balanced situation between these two chemicals:

- New processes yielding chlorine without caustic soda. For example, a relatively larger proportion (it's now about 10%) of chlorine could be made without caustic if demand for metallic sodium soars.
- New processes using nonchlorine materials or byproduct HCl instead of chlorine. These will increase in number and importance but their innovation may be gradual.
- New uses for NaOH.
- Using caustic soda at the expense of soda ash.
- Converting caustic soda to ash.
- Reducing production of lime-soda caustic. (This production will probably continue to decline but will not be eliminated for some time.

All these adjustments hinge on technological development in process substitution and in product substitution. And on the economic laws governing demand, supply and prices—which usually work toward a

*Meet your authors on page 370.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Chlorine-Caustic End-Use Pattern for 1956

Chlorine	Thousand Tons	Caustic Soda	Thousand Tons
Chemicals	3,000	Chemicals	1,155
Ethylene oxide and Glycol	330	Rayon & film	640
Carbon tetrachloride	240	Pulp & paper	285
Vinyl chloride	200	Export	257
Ethylene dichloride	200	Petroleum refining	284
Trichloroethylene	190	Lye & cleaners	161
Perchloroethylene	160	Textiles	135
Monochlorbenzene	180	Soap	80
Pulp & paper	563	Others	1,213
Sanitation	138		
Others	79	Total	4,210
Total	3,780		

balanced point.* Thus, any significant chlorine-caustic imbalance should prove only temporary.

Any long term forecast on products as complicated as chlorine and caustic soda should recognize all technical and economic factors to see if any obvious change would be in order. One thing is certain—long term forecasts of this nature are educated guesses at best.

▶**Chlorine Means Chemicals**—Total chlorine consumption increased from 339,000 tons in 1935 to 3,410,000 tons in 1955, a tenfold increase in twenty years. Chlorine-based chemicals increased 16 times in this same period.

About one-half of total U. S. chlorine consumption by chemicals in 1956 was concentrated in seven products, as indicated in the table above. Other chemicals which consume chlorine directly in their processes include: synthetic muriatic acid, synthetic glycerin, titanium tetrachloride, methylene dichloride, sodium hypochlorite, propylene glycol, bromine, chloroform, aluminum chloride, chloral and benzene hexachloride. Still others are: chlorinated camphene, dichlorotoluene, chlorinated paraffins, monochloracetic acid, ferric chloride, pentachlorphenol, kerylbenzene, trichlorobenzene, phosphorus trichloride.

▶**Outlets Up and Down**—Divergent growth trends of these products and their processes are two critical factors in the future growth rate of chlorine. Ethylene oxide, ethylene glycol and synthetic glycerin are good growth products but non-chlorine-using processes are becoming dominant. On the other hand, chlorine shows great promise in such products as titanium, zirconium and in phosgenation of isocyanates for polyurethanes.

Chlorine's continued growth is expected particularly in refrigerant and propellant manufacture. Plastics and resins, chlorinated solvents, pulp and paper, insecticides, herbicides, water chlorination and city waste disposal should all consume chlorine in increasing quantities.

Automotive fluids will show a steady growth unless piston engines are replaced by turbine engines in the near future.

If chlorine keeps growing at a rate of 10% a year, industry will have to up its capacity to 9 million tons a year by 1965, an increase of 5 million tons. Our analysis expects a more conservative rise of about 7% a year which will require an annual capacity of 7 million tons in 1965.

▶**NaOH Give-and-Take** — In analyzing caustic end uses (see table above) there is every indication that caustic soda growth will continue at the present rate (or even higher) for some of these applications. For caustic will remain a low price alkali with diversified, well established outlets.

As industrialization in South and Central America gains momentum, export shipments will probably accelerate. In our own country the pulp and paper industry's phenomenal expansions in the South and Pacific Northwest will likewise accelerate demand for caustic soda.

▶**Rayon Worries**—Competition of new fibers, particularly in tire cord, is threatening the future of rayon, and thereby caustic soda, as a material. There is, however, a considerable difference in expert opinions as to the extent of this threat. Technical improvement in the quality of rayon, future automotive fashion trends, and relative prices are considered key factors in deciding their ultimate position.

On the other hand, new uses like tufted carpets and improved cotton-rayon blended fabrics are stabilizing factors in the rayon industry.

If caustic soda keeps growing by roughly 7% a year, 7.7 million tons of additional capacity will be required in 1965. Our forecast is conservatively adjusted to 7.3 million tons.

* One way in which prices might work to keep things balanced: Relative prices of chlorine and caustic soda may widen slightly in the future while those between caustic soda and soda ash may narrow.

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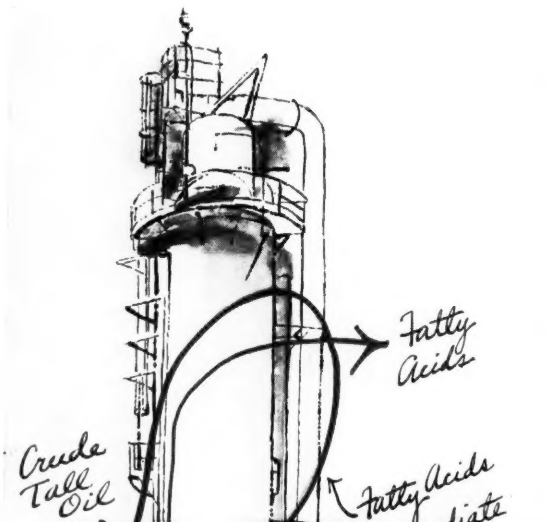
PRACTICE . . .

PROCESS FLOWSHEET EDITED BY T. P. FORBATH

Staged Distillation Process Splits Tall Oil

Crude oil, then its crude fatty acid fraction, feed bubble-cap tower on three-week cycles to get Union Bag's full line of tall oil products.

Unfold Flowsheet



With tall oil production thundering along at a furious pace,* seven companies in rapid succession have flocked into the business of splitting this kraft pulping byproduct into fatty acid and rosin fractions.

Among the latest is Union Bag-Camp Paper Corp., with its $2.5-million vacuum fractionation plant at Savannah, Ga., designed and built by Foster Wheeler.

Geared specifically for top-quality products and efficient performance, the new installation operates on an intermittent-continuous cycle abetted by a string of unusual design features. Moreover, it ties neatly into Union Bag's other operations at Savannah.

The plant handles up to 2,000 tons/mo. of crude tall oil from the black-liquor skimmings turned up at Union Bag's own nearby kraft pulp facility. And it teams with the 13-year-old tall oil acid-refining plant at the site to produce a complete roster of tall-oil-derived products. (Fatty acids, rosin, pitch and distilled tall oil now join acid-refined and crude tall oil in the company's Unitol line.)

▶ **Process Tailors Products**—Reports a company spokesman, "With this carefully engineered plant we can turn out the highest quality products, in a sense, tailored for market needs."

As an example he cites the tall oil fatty acid product. It analyzes more than 99% fatty acids and about 0.5% unsaponifiables. And the rosin product contains about 95% rosin and less than 3% unsaponifiables.

To turn in this handsome "tailoring" job, Union Bag runs a blocked operation designed around a single 125-ft.-tall bubble-cap fractional distillation tower.

First, crude tall oil feeds to it continuously and splits into rosin and a fatty acid intermediate cut. Then, after a three-week interval, the fatty acid intermediate stream takes over as tower feed and splits into tall oil fatty acids and distilled tall oil products.

▶ **Why Not Fully Continuous**—While a second distillation column to handle the crude fatty acid stream would make the plant fully continuous, any plant expansion thereafter would require duplication of facilities.

* In 1956, industry output hit about 550 million lb. Now some 750 million lb. is expected for 1957, and over 1 billion lb. predicted for 1958.

On the other hand, the single-column blocked plant can be expanded by adding only the equipment needed to carry out refining of the intermediate fatty acids. Too, the company believes, it's cheaper to build, operate and maintain a large blocked facililty at the capacity involved.

▶**Engineering Touches**—Tuning this blocked operation for product quality and operating efficiency are such engineering features as these:

- A 19,000-gal. tank car shuttles crude tall oil $\frac{3}{4}$ mile to the distillation plant. This is more economical than intermittently pumping crude through a 4,000-ft. insulated and steam-traced stainless steel pipeline.
- Side-entering agitators prevent stratification in feed and products storage tanks. This insures top uniformity of feed and of products.
- Inert-gas generators provide protective blankets for products storage tanks and tank cars. This practice along with aluminum construction of tanks, minimizes color pickup of products and so maintains their high quality.
- Control instruments, pumps and heat exchangers are grouped in centralized areas. This eases operating and maintenance problems.
- A plug-in telephone system throughout the plant facilitates communications, provides close control of all phases of operation.

▶**First-Stage Distillation**—Crude tall oil is pumped to a dehydrator, where moisture is evaporated. Sodium sulfate, which had been dissolved in the water, goes into suspension in the crude tall oil, so won't scale exchangers.

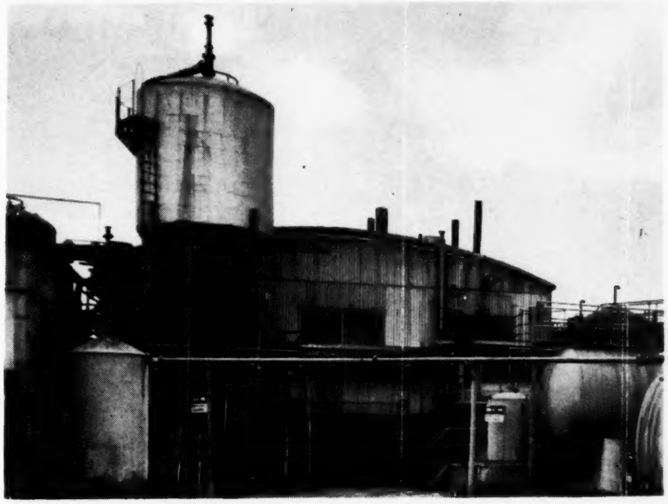
After steam heating, crude vaporizes in flash heater to feed a small stripping tower. There crude cracks into pitch bottoms, containing a large percentage of color contaminants and heavy unsaponifiables, and an overhead cut consisting of rosin, fatty acids and light unsaponifiables. This stripping operation occurs so quickly that heat-sensitive components aren't damaged despite high temperatures.

Overhead splits into three fractions in the main tower. A high intermediate cut of crude fatty acids contains rosin and requires rerunning. An overhead odor cut contains most of the undesired light unsaponifiables, with some low-molecular-weight fatty acids. Bottoms cut is product rosin stream for market.

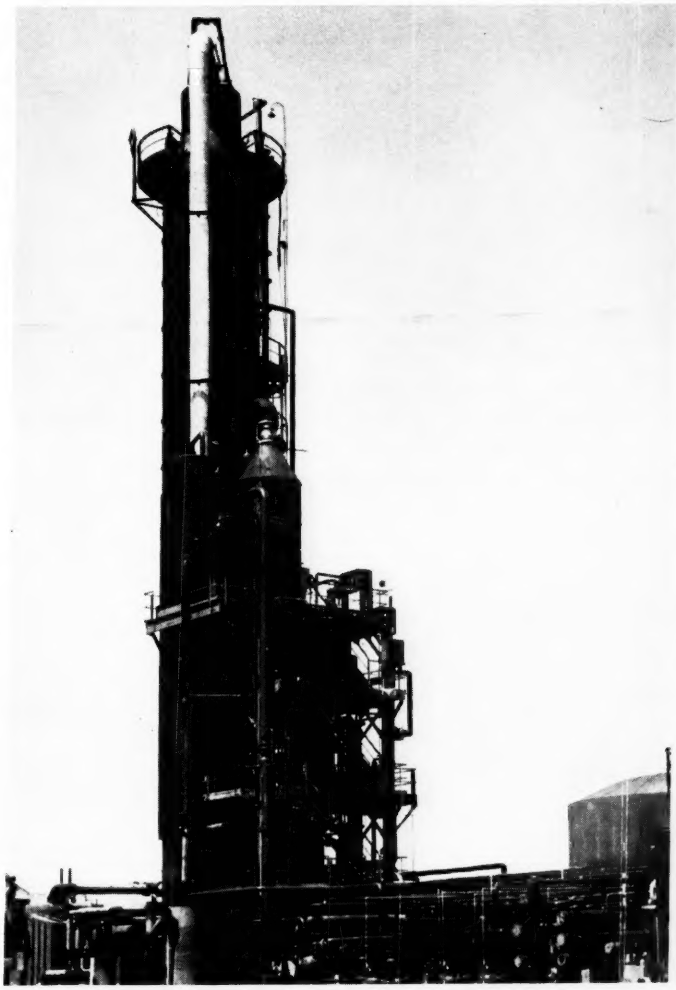
▶**Second-Stage Distillation**—Intermediate fatty acid fraction, collected during three-week first stage, is preheated and pumped to main distillation column. It splits into three fractions: Fatty acid product is tapped at a high intermediate plate; bottom product is distilled tall oil; an overhead odor cut removes unsaponifiables.

By changing operating conditions, Union Bag can shift production ratio between fatty acids and distilled tall oil, vary fatty acid and rosin content of distilled tall oil to meet market demands. While not specifying operating conditions exactly, the company reports that it runs the main distillation column in the range of 400-500 F.

Most heat supplied to the operation comes from oil- and gas-fired Dowtherm vaporizers. To prevent excessive corrosion by fatty and rosin acids at high operating temperatures, Union Bag uses Type 316 stainless steel throughout the plant as chief material of construction.

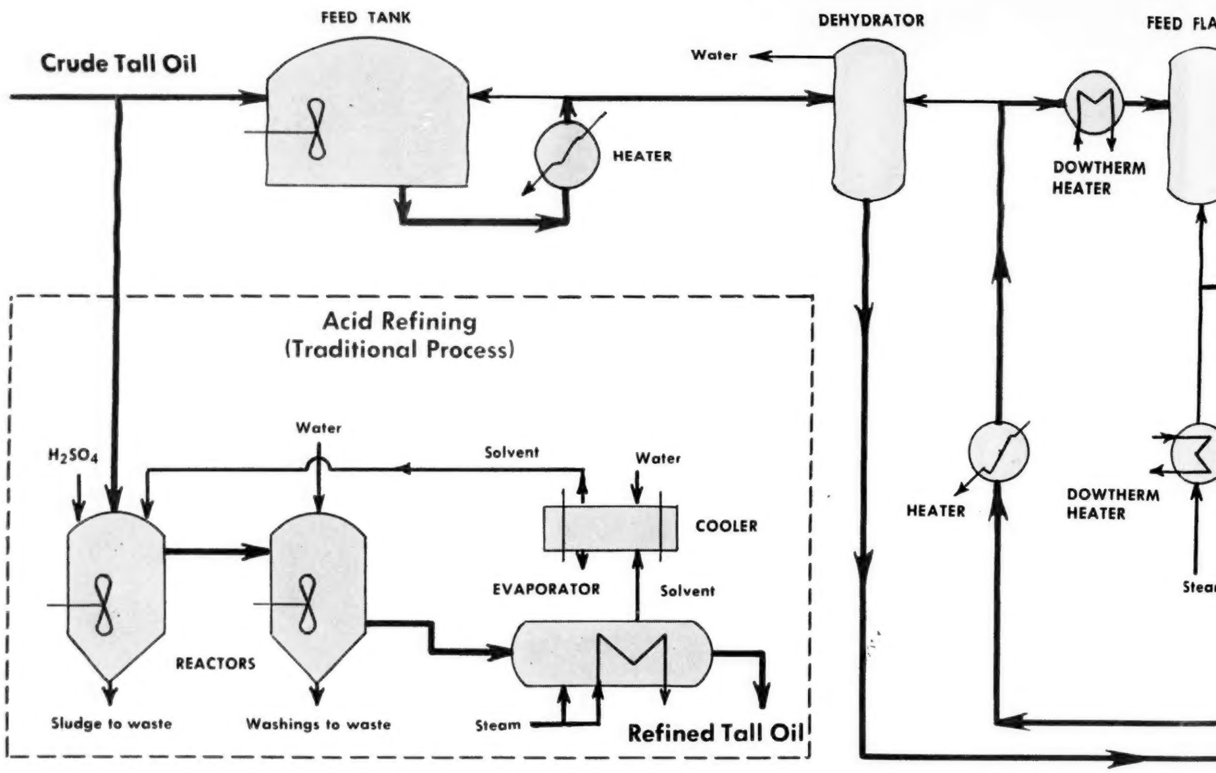


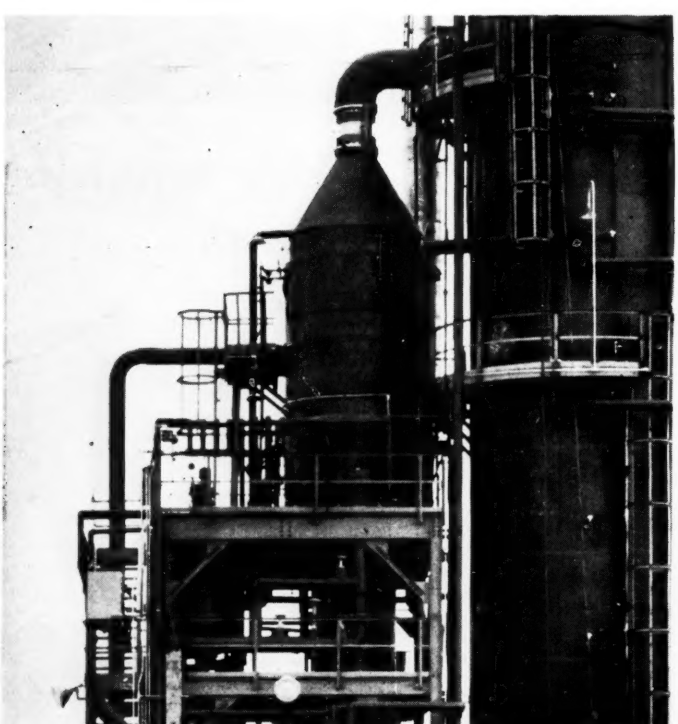
1 **ACID REFINING: Sulfuric treatment of crude oil in 15,000-gal. tank beats coloring, rosin crystallization of refined product.**



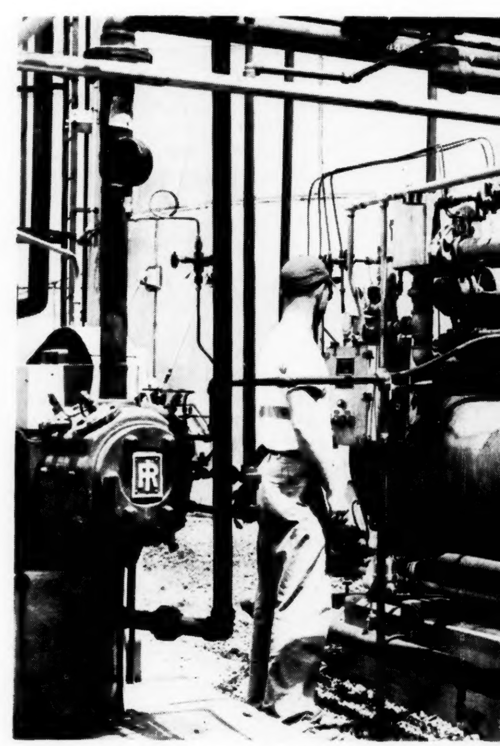
2 **DISTILLATION: 125-ft.-high bubble-cap vacuum tower continuously splits crude tall oil, then crude fatty acid fraction.**

-gal.
duct.





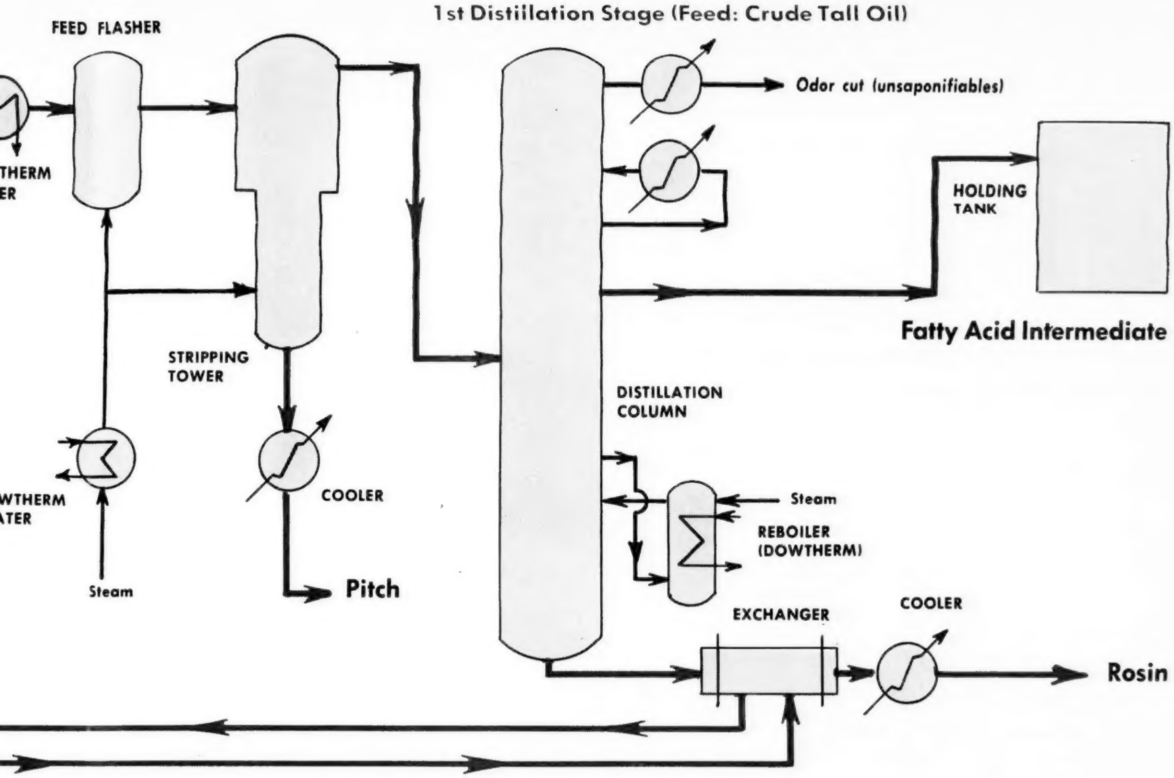
3 STRIPPING: Attached to main column, bubble-cap stripper cracks pitch product from crude oil feed before main distallation.

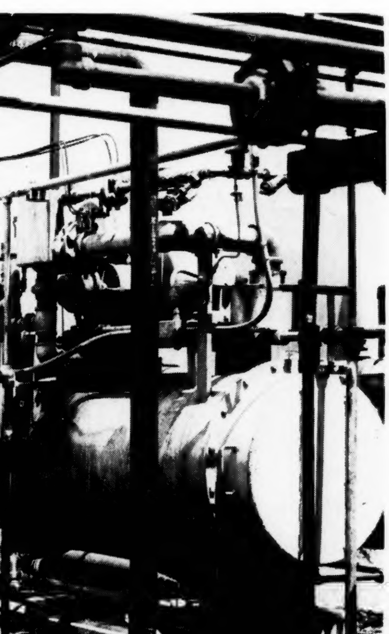


4 GAS GENERATOR: Burning oxygen from t gas blanket for product storage tanks to pre

con-
tion.

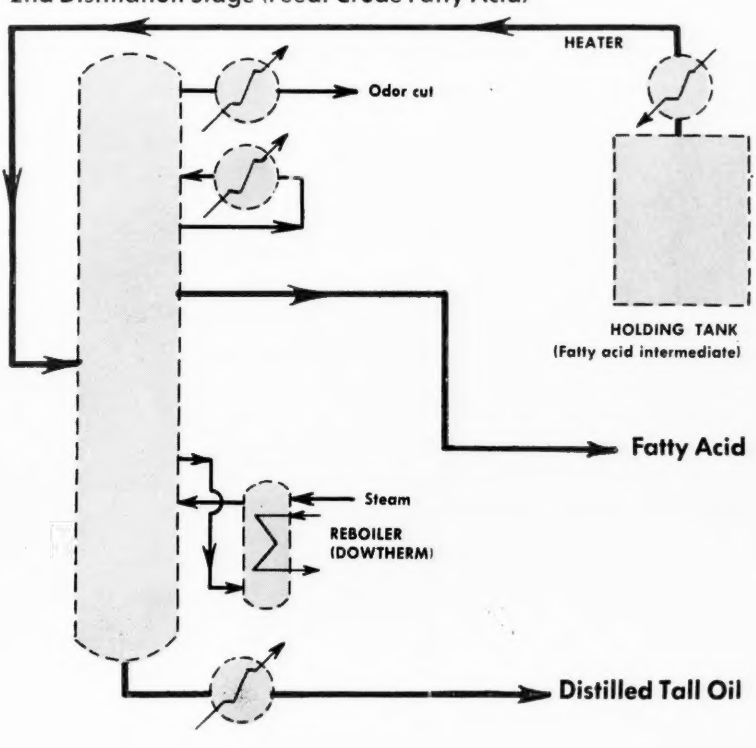
1st Distillation Stage (Feed: Crude Tall Oil)

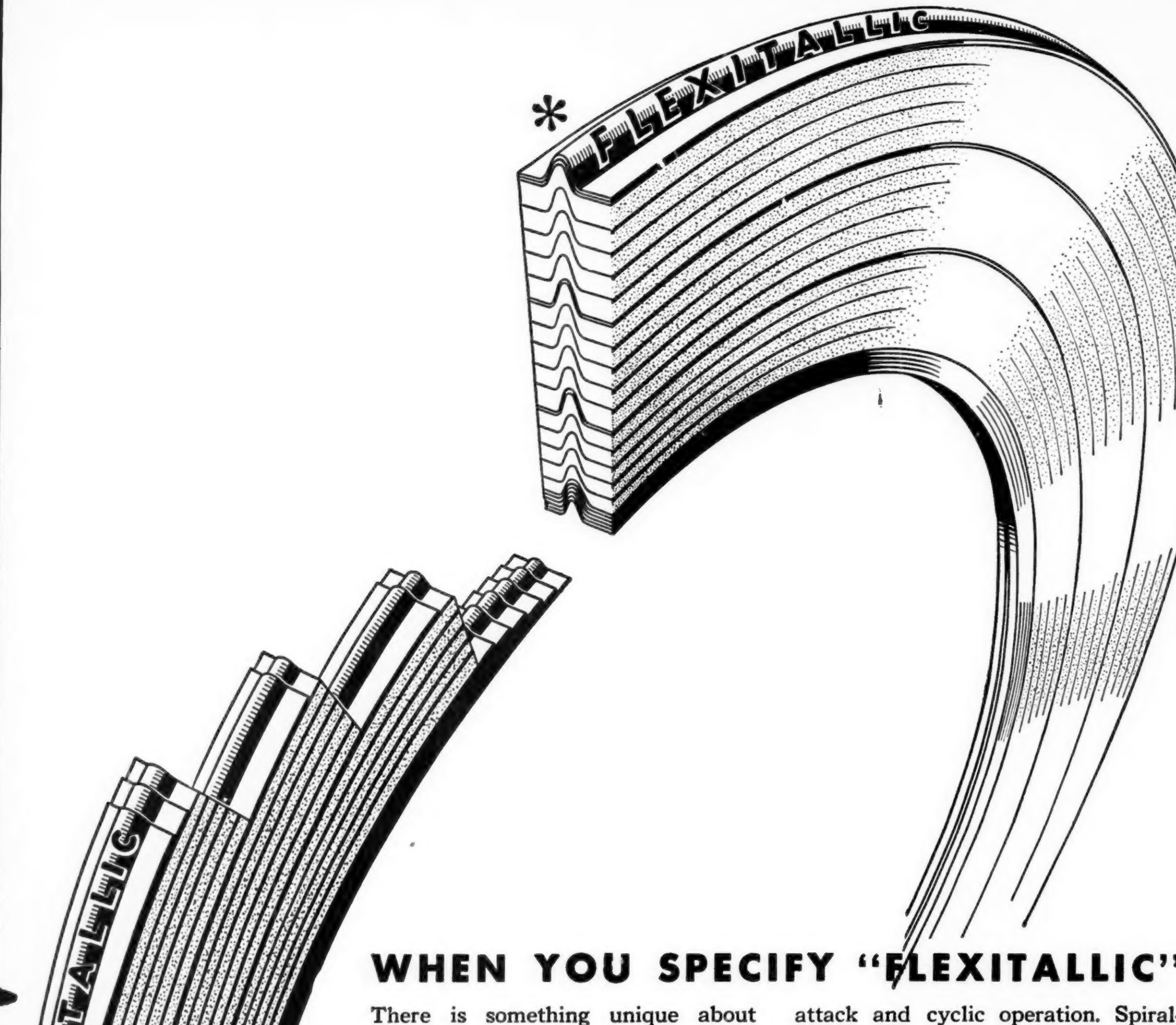




xygen from the air, unit supplies inert-
tanks to prevent color pickup.

2nd Distillation Stage (Feed: Crude Fatty Acid)





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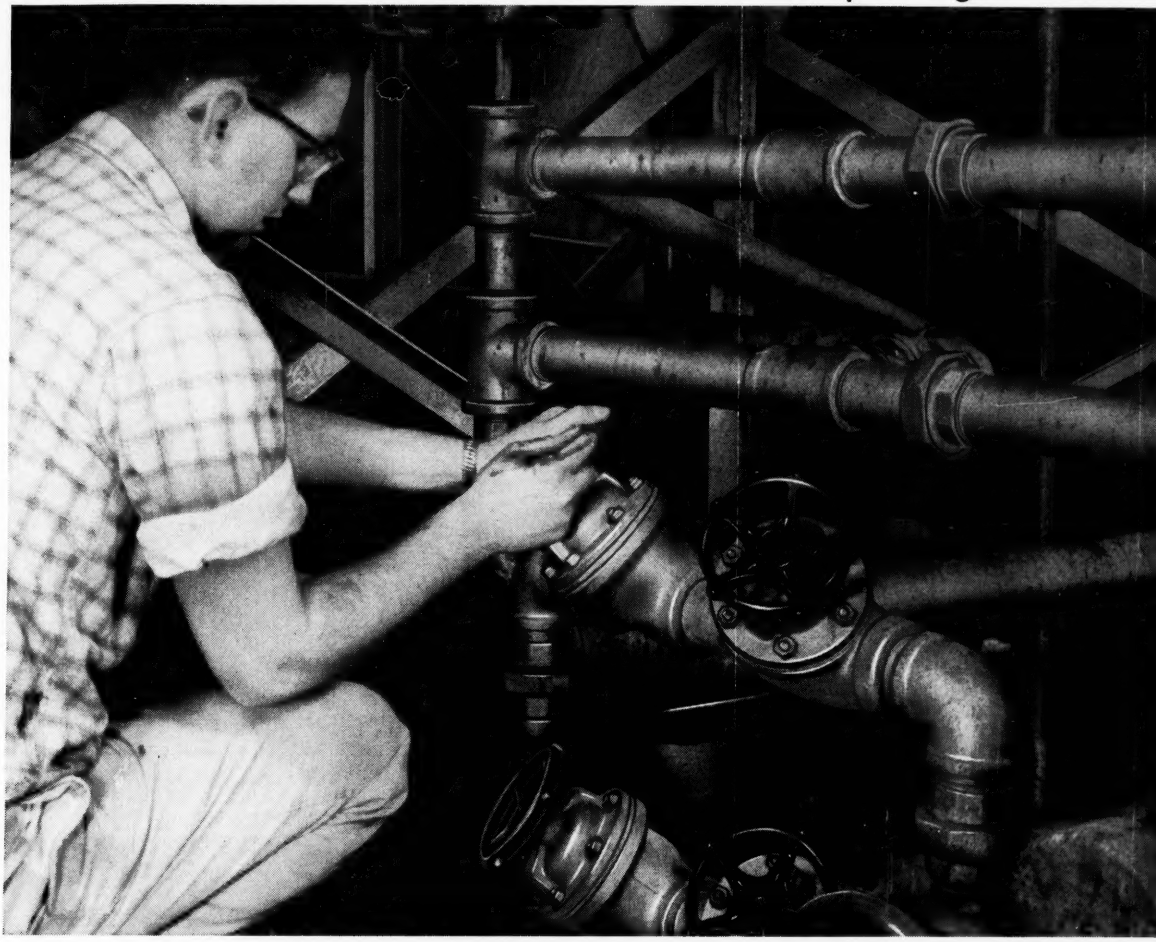

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JUNE 1957

Department Index

STAINLESS DIRECTORY

Buyers Guide to Ryerson Stainless Stocks & Services

Here's a quick guide to the nation's largest stocks of stainless steel—2,351 sizes, shapes, types and finishes of Allegheny stainless in stock at Ryerson.

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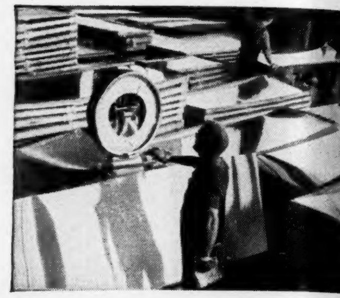
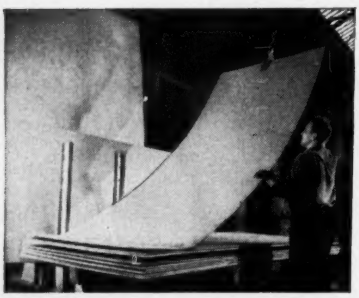
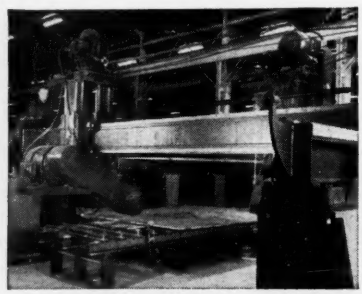
See your Ryerson catalog for a complete listing of stocks and call your nearby Ryerson plant for quick shipment of Allegheny stainless—one piece or a truckload.



SHEETS—11 analyses of Allegheny stainless sheets in stock including nickel and straight chrome types. Also extra wide sheets to reduce welding costs.



PLATES—Available in 9 analyses including plates to Atomic Energy Commission requirements and to ASTM specifications for code work. Also extra low carbon types for trouble-free welding.



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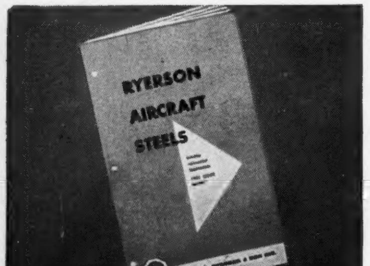

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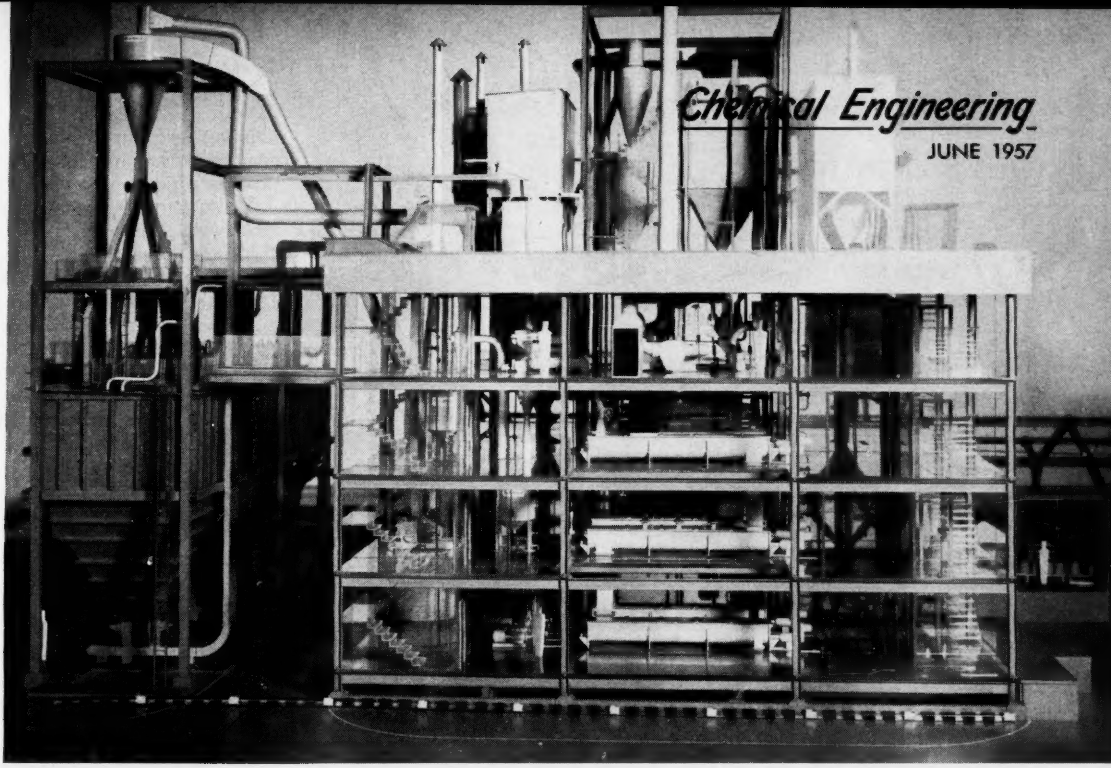


Reduce Costs With Scale Models

The Chemical Corps is sold on the use of scale models in chemical plant design. Here is how they have reaped savings in design, construction, operation, of solid and fluid processing plants.

S. P. SHUKIS and ROBERT C. GREEN, Chemical Corps Engineering Command, Md.*

As one of its functions, the Chemical Corps Engineering Command has responsibility for preparing plant designs for the manufacture of chemicals required by the Armed Services.

These chemicals call for large and complex plants. The Engineering Command is using models for many plant designs, with savings in design costs and engineering time.

There are many types of models, depending upon the particular design. Some are more applicable than others (see *Chem. Eng.* March 1954).

Generally, models are constructed in a series of nearly independent steps, sometimes referred to as model types. Many times, all the steps are not desirable, and some are bypassed, combined, or modified to suit the individual problem at hand.

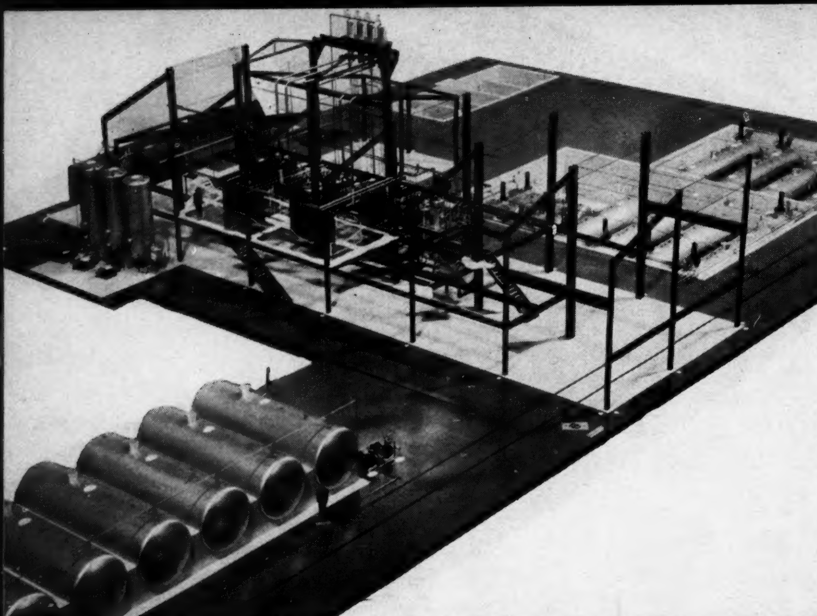
The usual steps or phases followed are basically: (1) factory area layout model, (2) equipment location model, (3) wire and disk piping model, (4) scaled piping model, and (5) as-built model.

- A factory area layout model represents a general layout of an entire or large section of a plant. The model is usually made to a small scale—⅛ in. equals 1 ft.—and is shown with a minimum of detail. It may, in fact, consist mainly of blocks or paper cutouts.

- The equipment location model is made to a somewhat larger scale—usually ⅜ in. equals 1 ft. It shows plant equipment in their proper location, and structural members of the plant building. The designer uses this model with an eye to locating pieces of process equipment most advantageously from the viewpoint of process repairs and maintenance, ease of operation, proximity of utilities, waste disposal, and transportation facilities. Design is very flexible at this stage, and changes can be made on the model.

Layout drawings, showing the location of plant equipment, are made from this model. At this stage the entire plant with equipment are shown except for piping and accompanying valves, fittings, instruments, and the like. This, when added to the model results in the wire and disk piping model.

*Meet your authors on page 372



FLUID HANDLING process plant model shows tanks, reactors, piping.

• On a wire and disk model, process piping, and sometimes utility piping, are represented by thin wires with small disks surrounding each pipe to denote outside line diameter, including insulation. Piping interferences are checked by noting clearances of the disks with other pipes and with structural members of the building. Using a mechanical flowsheet, the model maker installs piping under the supervision of a designer.

After all the piping has been shown on the model, and all interferences have been eliminated, piping drawings are prepared by taking the dimensions of pipe runs directly from the model. Using the piping drawings, full scale piping is then added to the model, and the result is the scaled piping model.

• A scaled piping model or check model shows plant equipment, building members, and all the process and utility piping, except very small lines, together with valves and major instruments installed in the lines. When design changes, made during later design or construction stages, are reflected on the model, the final model stage results in the as-built model.

• As-built model represents the plant as it is actually constructed and operated. If during operation, changes are made or additions constructed, these changes are reflected on the model. It, at all times, accurately represents the plant layout, equipment arrangements, and piping.

Models Used in Four Plants

The Chemical Corps Engineering Command has purchased models for incorporation into four plant designs. Other model contracts are currently being negotiated, in line with the policy of the Engineering Command to continue to make full use of this design tool.

Existing models have been of plants using two distinct types of processes. Two plants involved a fluid process; two involved processing of solids.

In the fluid process design, the models show tanks, pumps, and reactors together with piping for transferring process materials, supplying utilities, and removing wastes.

To insure proper inspection of the model all along the line, architectural features are handled with care. Walls, ceilings, and partitions are shown only in corner sections. Stairwells, elevator shafts, etc. are usually shown in outline form for visibility.

Structural members of the building housing the plant are shown only in enough detail to lend realism and to allow adequate checking of interferences. Floors are shown cutaway, except for room corners, to facilitate viewing interior portions of the plant.

In the solids processing plant, equipment consists of bins, reactors, dust collectors, mills and classifiers, blenders, and packaging machines. Much of the process material is handled by chutes and bulk flow conveyors, in addition to the usual process piping (*see photo, p.* 235).

These models, because of large size and compexity, were constructed in sections, so that each floor could be easily removed to facilitate inspection of the interior portions of the plant. Metal and plastic were used as model construction materials, to combine maximum strength and rigidity with minimum visual obstruction.

Advantages of Model

Many advantages are obtained through the use of a model in each of the phases of design, construction, startup, operation, and future addition.

Proper use of a model results in a superior design and a reduction of cost and time. The optimum layout of equipment can be readily obtained, since the designer is given a three-dimensional view. Inaccessibility of valves, instruments, and controls is eliminated, as are any safety hazards which might be overlooked in a two-dimensional picture.

Piping interferences are eliminated in the design stage, not during construction or startup, when their elimination is extremely costly. Fewer drawings are required, and the constant revisions necessary when interferences are located are largely eliminated. The first piping drawings together with any changes uncovered by the check model become final.

Savings also result in the construction phase. Contractors state that they might bid 10-15% lower if a model is available. This "ignorance factor" is usually added as a contingency against any hidden costs—particularly important to operations such as exist in the Chemical Corps, where much work is contracted and subcontracted, and costs pyramid from subcontractor to contractor to buyer.

In construction, order of installation of equipment can be determined more easily with a model on hand.

In difficult installations, actual "rehearsals" of the work can be carried out in the office to test methods of installation and determine adequacy of clearances with surrounding equipment. Using the model, crews can be oriented on the work they are going to per-

form. Scheduling of crafts can be more easily studied and planned on the model.

Preparation of operating directives and the training of operators are greatly facilitated. Operator training with the model can commence even before construction is complete, thus assuring a faster startup.

Even after the plant is completed and on stream, the model continues to be of value. It can be used in planning maintenance. This applies particularly in areas where it is difficult or impossible to see the actual equipment because of danger of toxicity, radiation or other hazards.

Today, in the chemical industry, plants are often modified because of new techniques, or expanded for added production capacity. The model can be a great aid in planning for future additions or modification of existing facilities.

The cost of a piped model usually will vary anywhere from 0.2 to 0.6% of the total installed plant cost. This figure naturally varies with the type and complexity of the process, materials of construction of the plant model, scale, amount of model detail, and the number of model phases. For a model of a multimillion dollar plant, this cost may seem high. But with proper utilization, many times this amount can be saved.

Constructing the Model

Models of multistoried plants shown to proper scale are sometimes so large that close study of their interior sections becomes difficult. It is possible to reduce the scale, but usually much of the model value is lost. Individual items lose detail and become so diminutive as to make accurate layout difficult.

A more satisfactory solution is to construct the model in sections. The model base can be segmented, and the building floors unitized so that they can be lifted off to view the interior. This requires proper choice of materials of construction for the model. Plastic, desirable because of its light weight, has the advantage of being transparent, yet strong. However, under normal lighting conditions, much glare may result if excessive plane surfaces are shown. Metal is also satisfactory, usually for the piping and building structure. But weight limitations may dictate the use of lighter weight materials.

Piping should be color coded, to facilitate tracing pipelines and understanding the process. This may be done either by using a standard coding procedure or by placing a special legend on the model base. Valve handles can be color coded as to method of operation.

Using Model

The Corps' experience has been that many individuals have little regard for the usefulness of models. Once the utility is evident and understood these individuals invariably become strong proponents of models. The first contact is important, and proper orientation of design personnel cannot be overemphasized.

One of the prime reasons for not using the model is lack of confidence in its accuracy. It is important that models be kept up to date and maintained in an accurate status at all times.

During some stages of plant design, more than one group may require use of the model. For this reason many model users have found it necessary to budget the time each group has with the model. Some firms have tried to overcome this by purchasing two models, but this is not too satisfactory because of expense involved and the difficulty of keeping both units exactly alike.

Since the use of the model gives the designer an opportunity to more completely envision the final form of his design, the overzealous designer may tend to continue to make minor design changes. The project director must be prepared to fix the design at some specific point and disallow further minor revisions. Otherwise, later stages of the project will be unnecessarily held up, and the final startup will be delayed.

Shipping and Storing

At the time of a national emergency, a need suddenly arises for production facilities with large capacities for the manufacture of agents and products for use in chemical warfare. During peacetime these facilities are not needed. But it is policy to maintain complete designs, so a minimum of time is required for plant construction. As a result of this policy, some of the Chemical Corps' designs, including the models, must be stored for indefinite lengths of time.


LABELS help in tracing process flow.

Since most of our design work is contracted to private industry, our models usually are constructed at the office of the contractor while he is preparing the design. Upon completion of the work, the model is thoroughly checked, corrected, packaged and finally shipped to the Chemical Center for storage.

We have found that a semipermanent type of shipping container is economically sound. This container should be designed for easy packaging, as models, while not extremely delicate, are fragile.

To facilitate packaging and transporting, the model should be constructed in easily handled sections. For economy of storage space, it is desirable to maintain standard base dimensions, thus permitting storage by a vertical stacking of the base units.

The model is an important tool to be added to the engineer's list of design aids. He can effect large savings in time, money, and required personnel by its proper utilization. It is especially important to the good designer, because he will carefully consider the problems involved and properly utilize this new implement. He will direct the model's use in such a way as to obtain maximum return for his investment.

New Statistical Method Rapidly

A new statistical technique for calculating optimum conditions works not randomly, but by approaching along the path of steepest slope to the summit. It can save much time and money in pilot or full-scale experiments.

S. I. NEUWIRTH, Consulting Statistician, and L. M. NAPHTALI, Polytechnic Institute of Brooklyn.*

A problem constantly faced by chemical engineers is that of determining optimum operating conditions for a process. Towards this end, effects of a number of variables must be experimentally evaluated. It might be required to find the conditions of time and temperature which will maximize the yield of a reaction, subject to the added condition that cost must be minimized.

We will review a new tool for optimizing, which has recently been developed and successfully applied to industrial problems. It is called the method of steepest ascent, or the Box-Wilson method. It minimizes the number of experiments required for determining an optimum point by taking the steepest slope path (in a number of sequential steps) to the summit. The method should be very valuable in pilot-plant or full-scale plant experimentation, where cost and time are major factors.

Our principle aim here is to make the reader aware of this important new statistical tool. We will not attempt to go into all the mathematical ramifications.

But to see where this technique applies, consider a typical chemical plant. When a proposed new product is ready for pilot study, company management has already made a substantial financial investment in the laboratory. They are convinced that it can be profitable and are therefore willing to make a major commitment in providing the plant facilities for full scale production.

The chemical engineer finds himself in the position of a middle man. To his left is the research group which has successfully uncovered a potential product of interest to management; to his right production and sales waiting to translate the product into company income dollars. Under these conditions, the engineer seldom has an opportunity to conduct exhaustive investigations. Yet he must provide reliable process information within these limitations. This is the type of situation for which the Box-Wilson method has been developed.

What's the Problem?

In general, the problem involves determining particular values or levels of the factors, $x_1, x_2 \ldots\ldots x_n$, which will maximize y in the function:

$$y = f(x_1, x_2, \ldots x_n) \qquad (1)$$

To illustrate, suppose we are dealing with a system in which we propose to maximize the yield of the product of a chemical reaction of the type:

$$A \xrightarrow[\text{concentration}]{\text{Temperature,}} \text{Product} \qquad (2)$$

If x_1 happens to be temperature and x_2 concentration, we may map a diagram of the reaction surface which might look like Fig. 1a.

Contours, such as those which appear in Fig. 1b, can be obtained by mapping the perimeter of the mound at levels of equal yield. The object of the engineer's work is the location of the top (or near-top) of the hill. If possible, we should like to accomplish this with a minimum of experimental effort—that is, without describing the entire reaction surface or mapping the entire hill.

Over the years, this problem of locating the summit has been approached in a variety of ways.

A method most commonly used is based on a plan to vary one factor at a time while holding others constant. With this approach an unnecessarily large number of experimental trials is usually required and the probability of accepting a false "peak" is rather high.

To illustrate this latter point, consider the two variable case in which the response surface is some form of rising ridge. Contours, such as those given in Fig. 2, are obtained by mapping the "perimeter" of the ridge at levels of equal yield.

If we first hold x_2 constant and vary x_1 along some horizontal line, say AB, we will deduce that E is the best level for the factor x_1. Then, we would hold x_1 at level E and vary x_2 along the vertical CD. The data would indicate that the maximum is between E and F. But a higher yield could have in fact been obtained in the upper left hand direction at a lower level of x_1 and a higher level of x_2.

If it happens that x_1 is the amount of a fairly expensive ingredient and x_2 a relatively less expensive factor such as reaction time, the experimenter and, in turn, management have taken a major step towards a serious financial mistake.

Another "classical" procedure is to select a number of combinations of x_1 and x_2 and then execute a series of experiments. This program is quite inefficient and can, too, lead to erroneous impressions.

If the selected combinations of x_1 and x_2 are too widely spaced with respect to the real character of the reaction system, the peak may be very easily missed, even with a very simple reaction system.

Simple two factor reaction systems are rarely encountered in actual practice. With increasing numbers of factors and complexity of reaction system, this kind of program markedly decreases in potential value.

How Box-Wilson Method Works

Generally, the problem of determining optimum operating conditions is one of properly designing an experiment, then analyzing and interpreting the results. We as-

*Meet your authors on page 372.

Determines Optimum Process Condition

sume, of course, that the experiment is executed exactly according to plan.

During the past several years, remarkable advances have been made, especially by British statisticians and chemists at first, in devising methods able to handle problems of this nature (Box, G.E.P., and Wilson, K.B., "On the Experimental Attainment of Optimum Conditions," *Journal of the Royal Statistical Society*, B, 13, p. 1, 1951; Box, G.E.P., "The Exploration and Exploitation of Response Surfaces," *Biometrics*, **10**, p. 16, 1954).

The technique has come to be known as the method of steepest ascent or the Box-Wilson method. This procedure assumes that the maximum can be reached by a rising path, after starting from some point away from the summit. A sequential program of experiments allow for the location of the near-optimum (sometimes called a near-stationary region for reasons which shall be clear later on).

Once near the summit, the experimenter can either (1) accept this provisional maximum as best because further experimentation is expensive relative to possible additional gains in, say, yield or because time is pressing. Or (2) he can continue with further exploration.

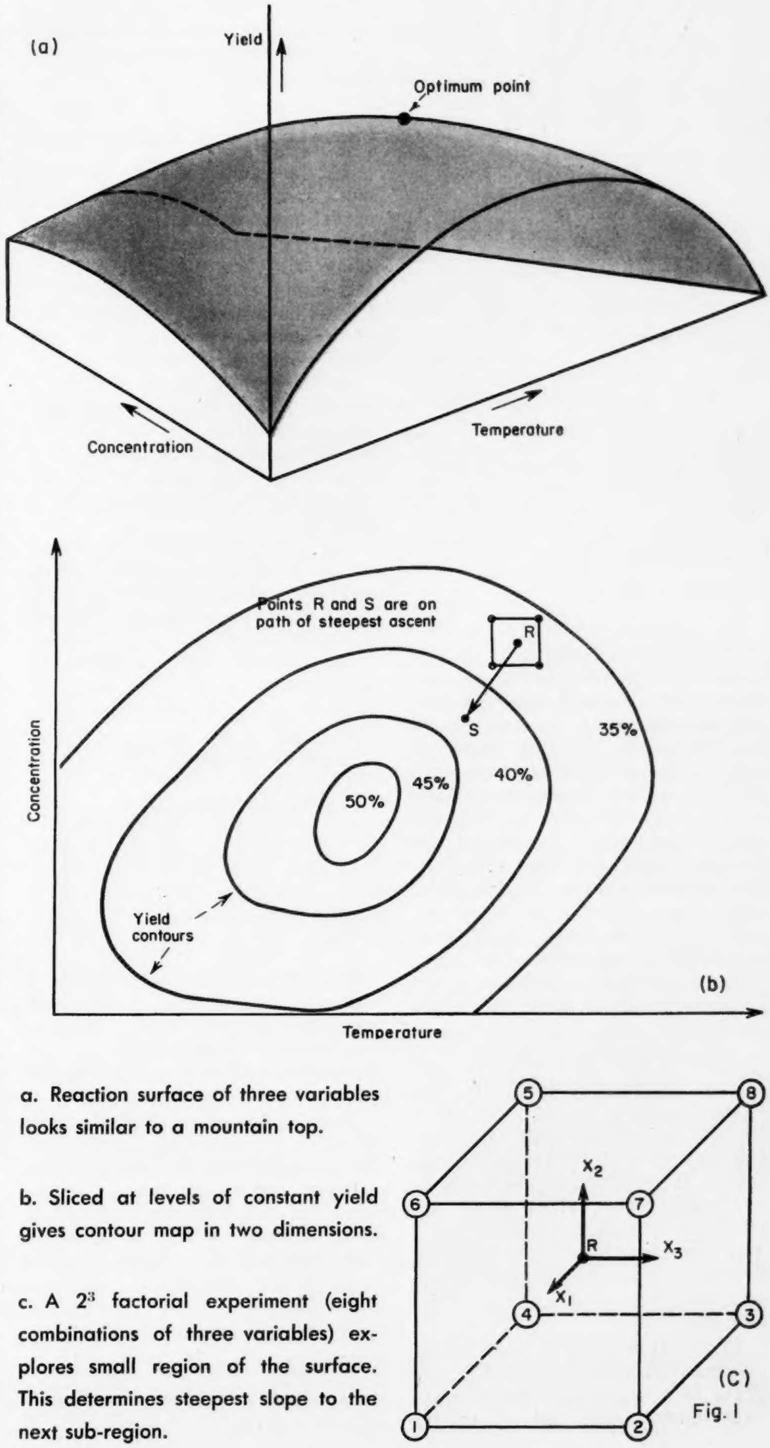
Case (1) seems to be the situation into which most industrial research falls. We shall restrict our discussion to this case. If further exploration is desirable, the two aforementioned references provide fine discussions.

Consider the problem of determining optimum conditions in a three factor case, x_1, x_2, and x_3. If y is yield, it can be related to the three factors by means of the equation:

$$y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{23}x_2x_3 + b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2 + \text{etc.} \qquad (3)$$

where the b slope values represent the coefficients obtained by fitting the equation to the data (regression coefficients).

If we start the experimental program at some point removed from the optimum, we can reasonably approximate the limited response



a. Reaction surface of three variables looks similar to a mountain top.

b. Sliced at levels of constant yield gives contour map in two dimensions.

c. A 2^3 factorial experiment (eight combinations of three variables) explores small region of the surface. This determines steepest slope to the next sub-region.

Fig. 1

Watch Out for False Optimums

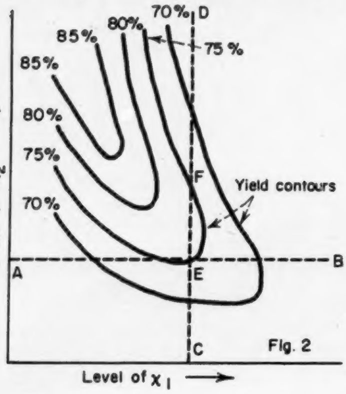


Fig. 2

"surface" by a linear function:

$$y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 \qquad (4)$$

Mathematically when a "surface" can be represented by Eq. (4), the direction in which the slope is greatest is given by the following relationships:

$$\Delta x_1 = k\, b_1$$
$$\Delta x_2 = k\, b_2$$
$$\Delta x_3 = k\, b_3 \qquad (5)$$

where k is a constant.

Remember, the technique explores only a small sub-region of the surface with a few experimental points. In this region, a low-degree polynomial represents the local surface. However, a variety of slopes are possible on the surface. The trick is to select the steepest slope, for that will go to the maximum more rapidly than any other.

If each of the factors in Eq. (4) is changed by an amount, Δx_i, (i = 1, 2 or 3), then the resultant change in response, Δy, is given by the following:

$$\Delta y = k\,(b_1^2 + b_2^2 + b_3^2) > 0 \qquad (6)$$

The response y must increase along this path—a path related to the values of the coefficients and the scale of each factor. As we approach the summit, or near stationary region, the values of the coefficients will each approach zero. The reader will recollect that the first derivitive of a function is zero at a maximum or a minimum point or value.

In actual practice b_i must be calculated from experiments. The program is a sequential one of small experiments, each set of experiments more closely approximating the near stationary region than the last. In other words, by determining the coefficients in a given trial, we may plan another trial by changing the levels of the variables in accordance with the magnitudes of the coefficients and the scale, along the hypothetical path of steepest ascent.

Factorial Design of Experiments

In the pilot plant or full-scale plant it is advantageous to design experiments so effects of each variable can be evaluated independently, along with the interaction* effects of a combination of factors. Statisticians have devised a general class of experimental designs to meet these goals—the factorial design.

In applying the Box-Wilson method to find the near stationary region, factorial experiments with two levels of each factor are most often used. Both levels of each factor are run in combination with all others.

To illustrate, suppose we wish to design such an experiment in the catalyst, temperature, agitation problem. A scale would be selected for each factor and points selected at both ends of the scale. Let these levels be C_1 and C_2 for amount of catalyst, T_1 and T_2 for temperature, and A_1 and A_2 for rate of agitation.

Eight combinations are possible:

Trial	Catalyst	Temp.	Agitation
1	C_1	T_1	A_1
2	C_1	T_1	A_2
3	C_1	T_2	A_1
4	C_1	T_2	A_2
5	C_2	T_1	A_1
6	C_2	T_1	A_2
7	C_2	T_2	A_1
8	C_2	T_2	A_2

The above design is called a 2^3 factorial experiment—three factors, each at two levels. This experimental design enables us to determine and measure the significance of the following:

Main effect of catalyst, C; main effect of temperature, T; main effect of agitation, A; interaction of catalyst and temperature, CT; interaction of catalyst and agitation, CA; interaction of temperature and agitation, TA; interaction of catalyst and temperature and agitation, CTA.

* The effect on say y of changing x_1 is dependent on the level of x_2. This is called an $x_1\, x_2$ interaction. Another way of looking at it: $y=f(x_1x_2)$. But this does not equal $f(x_1)+f(x_2)$.

Note that every combination of factors was run. The required number of trials in the full factorial experiment increase exponentially as the number of factors increase. If six factors are to be investigated, each at two levels, we would run a 2^6 factorial, which needs 64 combinations.

This is a prohibitive number of trials for a single experiment; it becomes even more untenable in a sequential program of experiments such as the Box-Wilson program. For these cases, modified factorial designs have been developed which need a considerably smaller number of trials. The technique known as confounding the factorial design is used. By confounding, the experimenter willingly eliminates measures of certain interaction effects (usually those which he considers unimportant compared to the others). For a splendid discussion of the factorial design (and the Box-Wilson method), the reader is referred to a book edited by Owen L. Davies, "The Design and Analysis of Industrial Experiments," Oliver & Boyd, London, first ed. (1954).

To simplify the arithmetic it is advisable to transform the scale of each factor so that the origin, 0, is the center of the design and the lower and upper level for each variable is -1 and $+1$ respectively. Fig. 1c describes geometrically a typical 2^3 design. An experimental point is located at each vertex of the cube.

Transformation so that the origin is the center of the design is accomplished by an algebraic manipulation.

For example, suppose the scale on temperature is 20 C. and 28 C., the two selected levels. The center of the interval is 24, which shall be transformed to zero; 20 shall be transformed to -1, and 28 to $+1$. The transformed, or coded, lower level T_1' is

$$T_1' = \frac{20\text{–}24}{4} = -1$$

and the transformed upper level, T_2', is

$$T_2' = \frac{28\text{–}24}{4} = +1$$

This is performed for each factor studied.

The transformed factor levels allow for greater ease in the calculation of the various regression co-

Calculating Path of Steepest Ascent—Table II

	Catalyst, Grams x_1	Temperature, C. x_2	Agitation Cyc./Min. x_3
1. Base level	6	25	30
2. Coding unit	2	5	5
3. Slope, b	+ 5.25	− 0.50	+ 2.25
4. Coding unit x slope	+10.50	− 2.50	+11.25
5. Change in level per 3 gram change in x_1	+ 3.00	− 0.71	+ 3.21
6. Path of steepest ascent	6.00	25.00	30.00
	9.00	24.29	33.21
	12.00	23.58	36.42
	15.00	22.87	39.63
	18.00	22.16	42.84
	21.00	21.45	46.05
	24.00	20.74	49.26

efficients by means of the formula:

$$b_i = \frac{\sum y x_i}{\sum x_i^2} \qquad (7)$$

How to Compute Optimum

To illustrate the computational technique, suppose a 2^3 factorial experiment with amount of catalyst, temperature, and rate of agitation had been performed. The data would appear in the form of Table I. Then

$$b_1 = [(-1)(y_1) + (-1)(y_2) + (-1)(y_3) + \ldots + (+1)(y_8)]/8$$
$$b_2 = [(-1)(y_1) + (-1)(y_2) + (+1)(y_3) + \ldots + (+1)(y_8)]/8$$
$$b_3 = [(-1)(y_1) + (+1)(y_2) + (-1)(y_3) + \ldots + (+1)(y_8)]/8$$

If $y_1 = 30$, $y_2 = 36$, $y_3 = 31$, $y_4 = 34$, $y_5 = 43$, $y_6 = 47$, $y_7 = 42$, and $y_8 = 45$, application of Eq. (7) yields:

$$b_1 = +46/8 = +5.75$$
$$b_2 = -\ 4/8 = -0.50$$
$$b_3 = +18/8 = +2.25$$

Interaction effects, also determined, were negligible. A b_o equal to 38.50 is calculated as the average yield over the eight trials.

Therefore, the response "surface" of yield can be approximated by:

$$y = 38.50 + 5.75\,x_1 - 0.50\,x_2 + 2.25\,x_3$$

Examination of the magnitudes of the regression coefficients immediately indicate the direction of the path of steepest ascent. Increase levels of x_1 and x_3 and decrease x_2 as a function of the b value. A hypothetical path of steepest ascent can now be determined in terms of specific combinations of the levels of the three factors.

Table II indicates the computation. Lines 1-4 follow by arithmetic. Line 4 gives the coefficients when the x's are transformed into their original units. In line 5 we determine the change in all factor levels for an arbitrary change in one of them. In the above illustration, we determined the change in temperature and agitation levels for a 3-gram increase in catalyst by making them proportional to line 4. Thus the change in temperature is $(-2.50/10.50) \times (3.00) = -0.71$.

This procedure, although arbitrary, uses the engineer's experience and knowledge in making a wise choice. A poor choice means that it will take a little longer to reach the maximum value. But even a first trial will show you what direction to take. The hypothetical path of steepest ascent is then calculated by successively adding or subtracting the values in line 5 to the base levels shown in line 1 (6, 25, 30).

The successive combinations of levels of factors in this hypothetical path of steepest ascent do not necessarily represent combinations which will indefinitely produce higher and higher yields. At some point we will presumably pass near a combination better than any other.

Following the construction of Table II and the determination of the hypothetical path of steepest ascent, it is advisable to run two or three lab or plant confirmatory trials at different points along the path and check the yields against those obtained in the first series of runs.

This will enable the experimenter to select new base levels for the second full set of factorially designed trials—in this three factor case, eight more trials. He may retain the same scale on each factor or change them. If the latter alternative is selected, he should transform the lower and upper levels of the new scale to −1 and +1 in a manner similar to the above example.

In the confirmatory trials one expects to obtain yields greater than those of the first set of trials. If the confirmatory trials do not result in better yields, the experimenter should carefully review the entire experimental program. Among the causes could be (1) some important unidentified variable, (2) inappropriate selection of factor change in the calculation of the path of steepest ascent, (3) interaction effects which are significant, and (4) inappropriate selec-

Setting Up the Experimental Design for Four Variables—Table I

	Catalyst, Grams x_1	Temperature, C. x_2	Agitation Cyc./Min. x_3	Yield % y
Range				
upper limit	4	20	25	
lower limit	8	30	35	
Base level (midpoint)	6	25	30	
Coding unit	2	5	5	
Trial 1	−1*	−1	−1	y_1
2	−1	−1	+1	y_2
3	−1	+1	−1	y_3
4	−1	+1	+1	y_4
5	+1	−1	−1	y_5
6	+1	−1	+1	y_6
7	+1	+1	−1	y_7
8	+1	+1	+1	y_8

* Equivalent to 4 grams: $(4-6)/2 = -1$

tion of scales in the second set of trials. The preceding list contains but a few of the possible causes.

Precautions to Follow

In applying this method, the engineer is cautioned in the following respects:

• The eventual success or failure of the experiments hinges on the ability to correctly identify the variables. The engineer, in consultation with his associates and the statistician, should thoroughly review all the possible variables.

On the basis of his experience, and tempered by possible budgetary limitations, he can select those which he considers most important. It sometimes occurs that an unaccounted variable, discovered after experimental work has been started, can completely disrupt and possibly negate all previous findings.

• With a large number of factors, there is the difficult problem of designing experiments within budget limitations. A complete factorial would, of course, require an impractical number of trials. If the experimenter cannot reduce the number of variables, it is necessary to run some variety of confounded design, where some selected interaction effects shall not be measurable.

All available sources of information must be exhausted in learning which of the interaction effects are likely to be negligible and therefore safe to confound.

• The concept of steepness involves distance. The path of steepest ascent is one which will give the maximum increase in response for a given distance moved by the independent variables.

However, when these variables are quantities which cannot be measured in terms of each other, the "distance" depends on the choice of scale. The distance between two points for which more than one variable is changed depends on this scale factor.

Thus, the direction of steepest ascent can be altered by changing the scales of the independent variables. The choice of the scale must be left to the individual experimenter and should be based on all the existing information at his disposal.

• When the results of the first set of experiments are obtained, it may occur that the coefficients of certain variables are small. This may indicate that these variables are without effect. It may also indicate that the levels chosen for these variables was already an optimum and that they are without effect only in a small region, or the levels may be a provisional optimum. That is, an optimum with respect to a certain choice of the other variables.

• Another possibility is that the scales chosen for variables with small coefficients were too small. For example, although temperature may have a strong effect on the yield of a certain reaction, if the levels chosen for the experiment were only a thousandth of a degree apart, the results would probably indicate a small temperature effect.

Thus, when the coefficients of certain effects are found too small in the first experiment, the levels should be shifted and the scales increased in subsequent experiments. If the variables are, in fact, without effect, the coefficients will continue to be small. If the levels were at a provisional optimum, the coefficients will appear significant in the next experiment. If the scales originally chosen were too small, the new coefficients will be larger.

• When using factorial experiments, the levels of the independent variables must be accurately known. They must be accurately controlled to the levels corresponding to -1 and $+1$ in the experiment design.

If they are accurately known, but cannot be controlled, a much more difficult method of analysis must be used, namely, multiple regression. If the levels of the independent variables are not accurately known, the problem becomes extremely complex and will require expert help from a professional mathematical statistician.

• For a particular reaction system, it may be that all the first partial derivatives vanish at more than one point. The function, while continuous, may be step-like. Therefore, when the regression coefficients all approximate zero, the experimenter should not immediately infer that this is the unique maximum. He should run several additional, confirmatory trials further along the hypothetical path of steepest ascent, determined in the last sequence of experiments, to verify the yields.

Further Study of Surface

When the experimenter has the opportunity and the budget to explore the reaction surface beyond the mere location of the near stationary region, equally powerful methods are available. The procedure involves closer investigation of the interaction effects. While the mathematics becomes more sophisticated (although a good part of it could be set-up mechanically), the possible additional gains can be quite substantial.

It is suggested that the reader familiarize himself with these methods. The references recited provide excellent discussions.

Plant size for carrying out the reaction is a significant variable, and it may interact with all other variables. Hence, locating optimum conditions in a pilot plant only locates a provisional starting point for a full plant. The refinements would be applicable primarily to a full scale plant, where "fine tuning" is required.

Summary of the Method

Although it has been successfully employed by chemical engineers with little or no formal training in statistics, the Box-Wilson method (as any other method) is useless if applied indescriminately. It does not substitute for common sense.

The experimenter's intuition and knowledge of the process are essential in identifying the variables and developing the experimental design. He must carefully choose the scale of variation for the independent variables and the center of the design. Further, it is his responsibility to interpret the results in the light of his knowledge of the process, thereby further advancing his insight into its behavior.

The methods and concepts described are in no way limited to experimental systems. Occasionally, a design problem involves so much calculation and is so complex that obtaining a result for a given set of values of the independent design variables is as difficult and complicated as performing an experiment.

It may be impossible or inconvenient to mathematically determine the optimum conditions for a design. In this case, the Box-Wilson method could be applied to the choice of the values of the independent variables for the design.

February	**Estimate Engineering Properties, Predict Thermal Conductivity** Why we are publishing this series. How the series is organized. Five top ways to estimate thermal conductivities of pure liquids.
March	**Predict Thermal Conductivity—II** Estimating methods that you can use for liquids, solids, solid-gas mixtures.
April	**You Can Predict Gas Conductivity** Experimental determination of thermal conductivity of gases involves some significant difficulties. Estimating methods for pure gases, gas mixtures.
May	**You Can Predict Heat Capacities** Thermodynamics is the fundamental approach to estimates of heat capacities.
This Issue	**Use Available Data to Estimate Heat Capacities** Best Method—Pick a value from someone else's tabulations. • Here are the key compilations for liquids, gases and solids. Next Best Method—Select an empirical correlation equation. • Here's a collection of empirical correlations for calculating heat capacities of liquid and vapor petroleum fractions, and pure hydrocarbons. If You Must Estimate—Methods you can use for • Mixtures • Solids
Coming Soon	• Estimation Methods for Liquids • Estimation Methods for Gases
Future Issues	**Other Engineering Properties** Estimation methods for other important physical properties.

You Can Predict Heat Capacities

WALLACE R. GAMBILL, Carbide & Carbon Chemicals Co., Charleston, W. Va.*

When you are looking for a clue to the heat capacity of a new material—or of a material that you have not worked with before—you'll want to check some sources of heat capacity data.

In keeping with the general theme of this series of articles, we will not include extensive tables of data on heat capacities. However, we will list some selected references.

We will also present a tabulation of empirical expressions that you can use to calculate the heat capacities of liquid and vapor petroleum fractions and pure hydrocarbons.

* Mr. Gambill is now with the Union Carbide Nuclear Co., Oak Ridge, Tenn. To meet your author see *Chem. Eng.*, Feb. 1957, p. 324.

Sources of Data

Familiarization with these key compilations will lead the interested reader to the hundreds of individual studies and articles upon which they are based.

Heat capacity data for 100 *gases* have been collected by Kobe and his coworkers as a 21-part series of articles in *Petroleum Refiner*, Jan. 1949 through Dec. 1951; Aug. 1954, p. 109; and Nov. 1954, p. 161. Ellenwood, Kulik and Gay reported results for eight common gases in "The Specific Heats of Gases over Wide Ranges of Pressures and Temperatures," *Cornell Univ. Engr. Expt. Sta. Bull.*, No. 30 (1942).

Data for heat capacity of gases collected by API research project 44 up to Jan. 1, 1953 have been published as "Selected Values of Physical and Thermodynamic Properties of Hydrocarbons and Related Compounds," Carnegie Press, Pittsburgh, Pa. (1953).

And a fundamental collection was made in 1924 of all values to that date by Partington and Shilling in "The Specific Heats of Gases," Ernest Benn, Ltd., London (1924).

For *liquids*, there appears to be no convenient compilation of heat capacities similar to those for gases. Of course, we can recommend the usual engineering and chemistry handbooks. But we can give only one specific reference:

Timmermans, J., "Physico-Chem-

Empirical Correlations for Heat Capacity at Constant Pressure—Table I

Class of Compound	Application	Correlation Equation
Mixed vapors[2]	Petroleum vapors	$C_P = \frac{(4.0 - s)(t + 670)}{6,450}$
	Petroleum vapors	$C_P = (0.0450K - 0.233) + (0.440 + 0.0177K)(10^{-3})t - 0.1530(10^{-6})t^2$
	Petroleum vapors	$C_P = \frac{0.388 + 0.00045t}{s^{0.5}} - \frac{0.09}{s}$
Pure hydrocarbon vapors[2]	Paraffins and olefins	$C_P = 2.56 + 0.51n + (0.0013n^2 + 0.0044n - 0.00065mn + 0.00495m - 0.0057)T$
	n-Paraffins	$C_P = 4.0 + 1.3n + 0.012nT$
	Higher paraffins	$C_P = 1.74 + 1.74n + 1.33m + (0.003545m + 0.00864n - 0.00486)t$
Mixed liquids	Petroleum oils	$C_P = [(0.06811 - 0.308s) + t(0.000815 - 0.000306s)] \times (0.055K + 0.35)$
	Petroleum oils	$C_P = \frac{(0.388 + 0.00045t)}{s^{0.5}}$
	Petroleum oils	$C_P = \frac{(2.10 - s)(t + 670)}{2,030}$
	Petroleum oils	$C_P = (\frac{1}{3}s^{0.5}) + 0.000389t - 0.0229$
	Petroleum oils	$C_P = 0.41/s$
Natural solids	Anthracite and bituminous coal	$C_P = 0.2 + 0.00088t + 0.0015V$
	Sand, crushed rock and similar materials[5]	$C_P = 0.18 + 0.00006t$

ical Constants of Pure Organic Compounds," Elsevier Publishing Co., Inc., New York (1950).

For *solids*, see the very extensive bibliography by J. R. Partington in "An Advanced Treatise on Physical Chemistry," Vol. III, pp. 311-321, Longmans, Green & Co. (1952). If you are considering an inorganic solid, check Kelley's work reported in *U. S. Bur. of Mines Bulletin* 350 (1932) and 371 (1934), especially the latter. There are also some values for solids in "The International Critical Tables," McGraw-Hill Book Co., Inc., New York (1927).

Empirical Correlations

In the table above we've compiled empirical expressions that can be used to calculate the heat capacities of liquid and vapor petroleum fractions and pure hydrocarbons.

As stated in Footnote 2, the C_P equations for vapors apply only at low pressures. Two miscellaneous correlations for natural solids appear at the end of the table. Below the table we have indicated pertinent references; superscript numbers refer to the footnotes.

Table I (Continued)

Units				Accuracy	Tested Range	Ref.
C_P	s	t	Other			
$\frac{\text{Btu.}}{\text{lb.-°F.}}$	Where used, s in each case is the specific gravity of the liquid at 60/60 F.	F.	....	Average is 1.33%	t from dew point to 350 C. ; s from 0.68 to 0.90	1
$\frac{\text{Btu.}}{\text{lb.-°F.}}$	For vapors, this is for the liquid corresponding to the condensed vapor.	F.	K = UOP or Watson characterization factor[3]	Good for $K = 11.8$	t from 0 to 1,400 F.	2
$\frac{\text{Btu.}}{\text{lb.-°F.}}$		F.	....	Average is 3%	Approx. same as first above	3
$\frac{\text{Btu.}}{\text{lb. mole-°F.}}$		K.	n=carbon atoms/molecule; m=H atoms/molecule	1–4% to 400 K.	For n equal to or greater than 3	4
$\frac{\text{Btu.}}{\text{lb. mole-°F.}}$		K.	n=carbon atoms/molecule	....	For $n \geqq 3$; and for $T \geqq 400$ K.	5
$\frac{\text{Btu.}}{\text{lb. mole-°F.}}$		C.	m and n as given above	Not thoroughly tested, tentative proposal	For $n \geqq 3$	6
$\frac{\text{Btu.}}{\text{lb.-°F.}}$		F.	K=UOP or Watson characterization factor[3]	3% avg., except near critical state or at pressures that permit vaporization	Broad range[4]; t from 0 F. to T_r of 0.85	7
$\frac{\text{Btu.}}{\text{lb.-°F.}}$		F.	....	2% avg., 4% max. for 30 oils. 5% avg. for 400–750 F.	t from 32 to 400 F.; s from 0.75 to 0.96	3
$\frac{\text{Btu.}}{\text{lb.-°F.}}$		F.	....	2.3% avg. at 240 F.	t from 50 to 430 F.; s from 0.75 to 1.00	8
$\frac{\text{Btu.}}{\text{lb.-°F.}}$		F.	....	....	....	9
$\frac{\text{Btu.}}{\text{lb.-°F.}}$	At given temperature	..	....	Rough rule of thumb	For $s \geqq 0.55$	Anon.
Btu./lb.-°F., ash-contained basis	....	C.	V = wt. % volatile matter	....	....	10
$\frac{\text{Btu.}}{\text{lb.-°F.}}$	....	F.	....	Approx. 20%	....	3

Footnotes—1. For various graphical presentations of these relations and of experimental data, see the following sources: Maxwell, J. B., "Data Book on Hydrocarbons," pp. 88-93 (1950); Bauer, C. R. and J. F. Middleton, *Petroleum Refiner*, **32**, pp. 111-114 (1953); Holcomb and Brown, *Ind. & Eng. Chem.*, **34**, p. 595 (1942); and Edmister, W. C., *Petroleum Refiner*, Nov. 1948.

2. All equations for vapors are for low pressures only, say a 0 to 50 psia. range.

3. K=Average boiling point of mixture in deg. R. to the 0.333 power and divided by s, the specific gravity of the liquid at 60/60 F. See Ref. 7 for special method of evaluating average boiling point for wide boiling ranges.

4. Equation was checked thoroughly by Gaucher for a wide variety of petroleum fractions and range of conditions.

5. Was proposed by Cragoe for solids content of petroleum asphalts. Based on data from "International Critical Tables" for marble, granite, Bentonite, cement mortars, sandstone, limestone, etc.

References—1. Bahlke, W. H., and W. B. Kay, *Ind. & Eng. Chem.*, **21**, p. 942 (1929).
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Numerical Coordinates for the Debye Curve—Table II

T/θ	Molar C_V	T/θ	Molar C_V	T/θ	Molar C_V
0	0	0.30	3.615	1.00	5.670
0.025	0.0073	0.40	4.437	1.50	5.824
0.050	0.0580	0.50	4.913	2.00	5.884
0.075	0.1953	0.60	5.193	3.00	5.919
0.10	0.4514	0.70	5.383	4.00	5.937
0.15	1.269	0.80	5.515	5.00	5.940
0.20	2.198	0.90	5.604	∞	5.959
0.25	2.996				

Methods for Mixtures

Only a few simple rules are known for approximating the heat capacities of mixtures.

However, since this discussion applies equally to all combinations of mixed phases, we have included it at this point before proceeding to pure liquids, solids and gases.

The only recourse at present for calculating the heat capacities of mixtures of solids, liquids or gases —singly or in combination, miscible or immiscible—is to weight the pure component or phase heat capacities by weight, mole or volume fractions. The choice will be dictated by the units of the heat capacities being weighted.

For any immiscible mixture, this method is accurate. For miscible mixtures, the relation varies in its accuracy from excellent in the case of gases at low densities (where the molecules are far apart and there is little or no intermolecular interaction) to quite poor for liquid mixtures with large heats of mixing. The actual specific heats of such nonideal mixtures are larger than the values calculated by assuming additivity.

For liquids, the weighting rule will generally work well only for mixtures of chemically similar nonpolar liquids (such as hydrocarbons or liquid metals), or for aqueous solutions of nonelectrolytes.

Aqueous solutions of inorganic salts are a special class. Here, two rules-of-thumb are available:

- Kern[1] recommends that the weighted specific heat be used, where the specific heat of the salt is for the crystalline state.
- Alternatively, for dilute solutions up to about 40 wt. %, the assumption has been made[2] that the dissolved salt has a negligible heat capacity. Thus, a 30-wt.-% solution of NaCl in water would have a specific heat of 0.7.

The specific heats of aqueous solutions generally decrease with increasing solute concentration, as would be expected from the high heat capacity of water.

A rigorous method for calculating the specific heats of liquid mixtures—ideal or nonideal—involves the use of partial molal quantities; but since these are calculable only from specific heat data for the given solution, the method has little practical value.

Nomenclature (Consistent Units)

C	Heat capacity
d	Differential operator
E	Internal energy
g_c	Gravitational constant
H	Enthalpy
J	Mechanical equivalent of heat
K	Compressibility
L	Latent heat of vaporization
M	Molecular weight
P	Absolute pressure
Q	Heat quantity
R	Universal gas constant
S	Entropy
T	Absolute temperature
U_s	Velocity of sound
V	Volume
β	Coefficient of thermal expansion
γ	C_P/C_V
μ	Joule-Thomson coefficient
ρ	Density
∂	Partial derivative of

Subscripts

H	At constant enthalpy
L	For liquid phase
s	At constant saturation
P	At constant pressure
S	At constant entropy
T	At constant temperature
V	At constant volume; and for vapor phase

Methods for Pure Solids

Method 1—Dulong and Petit

For crystalline solid elements, the atomic heat capacity in cal./gram atom-°K. may be approximated by the empirical law of Dulong and Petit.[3] This law, proposed in 1819, states that this value is about 6.2 for all such elements. (For metals only, 6.4 is a better value.)

The Dulong and Petit rule is fairly satisfactory for elements that have atomic weights above 40. The value is usually less than 6.2 for the light elements. This rule should be applied at room temperature or higher. However, there is no one temperature under which the law applies to all elements. Several elements which obey the law at ordinary temperatures give values as high as 9 cal./gram atom-°K, at their melting points.

Atomic heat capacities increase slowly with temperature, approaching the 6.2 value at elevated temperatures, even in the case of low-atomic-weight elements, and decrease rapidly at low temperature with temperature decrease, approaching zero at absolute zero.

Actually, the law has more significance—and gives slightly better agreement—when referred to constant-volume conditions. The constant has a maximum value, calculated theoretically by Boltzmann from classical kinetic relations for an ideal solid, of $3R$ or 5.96 cal./gram atom-°K. Substituting this relation, it is found that solids of atomic weight greater than 40 and at room temperature or higher have a $C_v = 5.9$ plus or minus 0.09.

This asymptotic value of 5.96 occurs at low temperatures for solids such as lead which are soft and malleable, and with a large atomic weight and low melting point. These properties indicate weak crystalline forces.

On the other hand, the occurrence is at much higher temperature for elements with opposite crystalline properties. At very high temperatures, if the material is still a solid the atomic heat capacity may exceed 5.96 because of the impartation of energy to electrons by high-level thermal agitation. This happens with materials like Na, Cu and Fe.

For solids, $C_P - C_V$ is a small fraction of either, and oftentimes no distinction is made between the two (however, see method of estimating given below). The law is usually stated as follows:

$$C_P = 6.2 \pm 0.4 \text{ cal./gram atom} - °K.$$

or,

$$C_V = 5.96 \pm 0.2 \text{ cal./gram atom} - °K.$$

Method 2—Kopp's Rule

Kopp's rule[3] applies to solid compounds. As developed by Neumann, Joule, Woestyn and Kopp (1831 through 1864), the rule states that the molar heat capacity at constant pressure and ordinary tempera-

tures can be approximated by assuming it equal to the sum of the atomic heat capacities of the elements that make up the compound.

Heat capacity contributions which can be used in making the summations are:

Carbon	1.8
Hydrogen	2.3
Boron	2.7
Silicon	3.8
Oxygen	4.0
Nitrogen	4.8?
Fluorine	5.0
Phosphorus	5.4
Sulfur	5.4
All others	6.2

It follows that, subject to the exceptions as given in the listing above, these equations can be used for this case:

$$C_P = 6.20\, n \text{ (cal./gram mole} - {}^\circ K.)$$
$$C_V = 5.96\, n \text{ (cal./gram mole} - {}^\circ K.)$$

where n is the number of atoms in the molecule.

Though reasonably accurate, this rule is empirical and inexact and errors of up to 20% are not uncommon. Good accuracy has been reported for glasses and amalgams, but the rule is irregular with alloys. Temperature dependency of heat capacity is not given by Kopp's rule, so it must be considered of limited applicability.

We might note here that, in general, heat capacities of compounds are higher in the liquid than in the solid state, and that at the melting point the two are approximately the same. If C_P of the solid has reached the Dulong-Petit value just below its melting point, the difference is small; if not, as for ice-water, the difference is generally large.

Method 3—Debye's Equation

For a theoretical justification of the above approximations, and for a tested relation for calculating the heat capacities of many solids in the low-temperature range (say 75 K. as a maximum), you should consult the simple Debye equation.[4]

While not of great practical importance in a direct sense, low-temperature heat capacities of solids are of interest in the evaluation of absolute entropy and in the third law of thermodynamics. Debye, who along with Einstein, Nernst, Lindemann, Born, Blackman and others, made important contributions to the theory of the solid state, derived an equation based on quantum theory. This equation estimates the molar heat capacity of crystalline solid substances due to lattice vibrations in the low-temperature range near absolute zero. The equation agrees surprisingly well with experimental data.

By assuming for the solid perfect elasticity and vibration as a single unit, Debye found that

$$C_V = 3R[f(T/\theta)]$$

where R is the universal gas constant; $f(T/\theta)$ is a complex integral function; T is absolute temperature; and θ is a characteristic temperature, the "Debye temperature."

As T/θ approaches infinity, the integral function approaches 1.0 and C_V approximates the value of $3R$, or 5.96 as mentioned above. As T/θ approaches zero,

$$f(T/\theta) \rightarrow (4\pi^4/5)\,(T/\theta)^3$$

so that, at very low temperatures,

$$C_V = 464.5\,(T/\theta)^3$$

where C_V = atomic or molecular heat capacity in cal./gram atom–° K., or in cal./gram mole–° K.; T is absolute temperature; and θ is a characteristic constant with units of absolute temperature.

This equation will give C_V as a function of T/θ for T/θ equal to or less than about 0.08. For the coordinates of the complete "Debye curve" evaluated numerically, see Table II on the previous page.

In general this correlation is applicable for all elements in the solid crystalline state and for many compounds in the isotropic crystalline state. It has been verified for monatomic solids, simple compounds crystallizing in the cubic system (including many metallic elements), and also for some metals crystallizing in the hexagonal system (such as zinc). The greater the value of θ, the higher the temperature for which the formula gives good results.

Upper limit is at a T/θ of 0.08 and is equivalent to about 75 K. for many substances. The general curve, of course, may be used to much higher temperatures, where the accuracy is often superior.

It's doubtful that the Debye relations apply to amorphous solids. For ionic and organic compounds of some complexity, the Debye and Einstein functions are often combined. Treatment of this combination is beyond the scope of this article.

Method 4—Assume No Difference

At 300 K. (room temperature) C_P approximately equals C_V for many substances. Actual magnitude of the difference of molar heat capacities at this temperature ranges from 0 for carbon and arsenic to 0.6 for potassium and 0.9 for iodine. Average is 0.212 for 42 elements, which indicates the approximate validity of the Dulong and Petit law for C_P:

$$C_P = C_V + (C_P - C_V)$$
$$C_P = 5.96 + 0.21 = 6.17$$

When you feel that the calcula-

Selected Values of Characteristic Constants for the Debye Relation—Table III

Element	θ, Deg. K.	a	Element	θ, Deg. K.	a	Element	θ, Deg. K.	a
Al	419	3.48	Ga	.....	0.91	Pd	275	31.0
Ag	229	1.54	Ge	290	.....	Pt	233	16.1
Au	175	.....	Hg	96	5.62	Rb	85	.....
Be	900	.....	In	106	3.23	Sn	260	3.7
Bi	111	.....	K	126	.....	Ta	247	14.1
C	1,860	.....	La	132.5	16	Th	168	13.3
Ca	226	.....	Li	510	.....	Ti	290	8.29
Cd	172	1.28	Mg	342	3.25	Tl	100	15.2
Co	443	12.0	Mn	410	42.1	U	.....	34
Cs	68	.....	Na	202	.....	V	374	17.3
Cr	400	3.74	Nb	250	21.0	W	169	51.5
Cu	335	1.78	Ni	413	17.4	Zn	320	1.44
Fe	462	12.0	Pb	90	8.92	Zr	265	6.92

tion of $C_P - C_V$ is justified, you can use Eq. (4d) from Table I of last month's article (*Chem. Eng.*, May 1957, p. 264).

If only linear coefficients of expansion and compressibility are to be found, the approximation may be made that

$$\beta = 3\,(\beta)_{linear}$$

and that

$$k = 3\,(k)_{linear}$$

This is strictly true only if the substance is isotropic. We can obtain the heat capacity ratio C_P/C_V once we know the difference between the two values because:

$$C_P/C_V = C_P/[C_P - (C_P - C_V)]$$

Eq. (4d) from Table I (see reference above) requires knowledge of the temperature dependence of the coefficients for use over a practical temperature range. Fortunately, an approximation is available to obviate this difficulty. If

$$A = V\beta^2/K_T C_P^2 J$$

Then,

$$(C_P - C_V)_{molar} = A\,C_P^2 T$$

where A is known as the Nernst-Lindemann constant and the equation is similarly named.

This constant is essentially temperature independent for a given substance and can be calculated from one value each of V, K_T, β and C_P at one convenient temperature. Nernst and Lindemann also found (1911) that A is approximately equal to $0.0051/T_m$, where T_m is the melting point in deg. K.

Alternatively, Lindemann and Magnus have formulated the empirical equation

$$C_P - C_V = a\,T^{1.5}$$

where a is a constant for each substance; and T is absolute temperature.

Watch Your Constants

In Table III on the previous page we have given values of the characteristic constant θ for use in the Debye relation. A constant a in units of 10^{-4} cal./(gram mole) (°K.)^2 is included in the table and will be explained below.

There is some disagreement as to these value of θ for the elements, with the values cited in Perry's "Chemical Engineers' Handbook," for example, being generally somewhat lower than those given by Zemansky in his book "Heat and Thermodynamics." Values for a few molecules are given below:

Compound	θ, Deg. K.
Iodine	106
Oxygen	126
Potassium bromide	177
Potassium chloride	230
Sodium chloride	281
Calcium fluoride	474
Ferrous sulfide	645

To Calculate the Constant

Debye characteristic temperatures may also be calculated from properties of a solid other than its heat capacity:

$$\theta = h\,\nu/k$$

where θ is in deg. K.; h is Planck's constant $= 6.624 \times 10^{-27}$ erg-sec.; ν is a characteristic vibrational frequency in reciprocal sec.; and k is Boltzmann's constant $= 1.3805 \times 10^{-16}$ ergs/deg. K.

A semi-empirical equation based partly on the supposition of Lindemann[5] that at the melting point the amplitude of vibrations of the atoms in a solid are approximately equal to their mean separation distance, is not only easier to use but also checks the experimental data more accurately:

$$\nu = (2.8 \times 10^{12})\,(T_m/M\,V^{0.67})^{0.5}$$

which, when combined with h/k and reduced to its simplest form, becomes:

$$\theta = 134\,T_m^{0.5}\,\rho^{0.33}/M^{0.83}$$

where θ is in deg. K.; T_m is the absolute melting point in deg. K.; ρ is the solid's density at T_m, grams/cc.; and M is the solid's atomic or molecular weight.

This relation may be expected to predict θ within about 8%. For carbon and about six metals, the maximum deviation is 15%. The atomic frequency, ν, has also been correlated with expansivities and electrical conductivities.

Method 5—Sommerfeld's Extension

It should be noted that the Debye relation breaks down for metals at *very* low temperatures, but holds for most nonmetals in this region. Solids of complex crystalline structure will also deviate from the law at very low temperatures.

An extension[4] of Debye's theory by Summerfeld on the basis of a theory by Fermi takes free electron motion into account and describes this very-low-temperature behavior of metals satisfactorily:

$$C_V = (464.5\,T^3/\theta^3) + aT$$

where a is a constant dependent on the number of free electrons per atom. This is the a that is given in Table III on the previous page.

In further generalizing, W. Nernst, G. N. Lewis and G. E. Gibson, among others, proposed modified forms of the Debye relation which are more applicable to compounds, but which are more complex.

Method 6—Kelley

In the ordinary range of temperatures, the temperature dependence of the heat capacity of solids is generally expressed by:

$$C_P = a + bT + cT^2$$

Kelley[6] has found the following form to be preferable:

$$C_P = a + bT + (c/T^2)$$

For More About Debye

The reader interested in further details of the Debye relation is referred to these five sources:

Zwikker[7] considers the problem generally in his book on solids. Landiya[8] has studied C_V for complex inorganic compounds. Calingaert[9] has pointed out an interesting relation. And Kelly[10, 11] and Binnie[12] have considered the calculation of the Debye characteristic temperature, θ, by various methods.

Next Month: Liquids

Pure liquids get the spotlight next month when we evaluate and summarize the major proposals that have been made on methods for estimating heat capacities of liquids.

In an early issue we'll discuss heat capacities of liquid metals, of fused salts and of gases.

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Chemical Engineering
JUNE 1957

Process Control

This special report on Process Control is the fourth in a cycle of coverage of this vital field which started in 1929. Significantly, these reports have been coming at ever-closer intervals: 1929, 1943, 1952 and 1957. That gives a fair indication of how control developments are accelerating.

Go back to 1929 and you are in the pioneer era of process control, with most of it pioneered by chemical process industries. There was virtually no literature. Control itself was just emerging from an almost embryonic state. There was little science, except perhaps in thermometry.

By 1943 control instruments had evolved markedly, but were just starting to tap the principles of electronics. Military necessity was now elevating the concept of feedback control to new heights. Electronic and communications engineers were hatching wartime miracles. Communications theory was building a new science of automatic control.

Between 1945 and 1952 some of these wartime developments and their creators were making their way into process control. With them they brought new language and new methods, and their bag of new tricks which included block diagrams, frequency response, a heightened respect for dynamic process and hardware analysis, not to mention the high speed computer.

Now in 1957 we begin to see where all this is leading. We are already in what Slater (p. 251) calls the era of Maximized control. We are sharpening the tools of dynamic analysis, analysis instruments, data digitizing and computing which eventually will lead to Optimized control. But the operator is still "in the loop" and control is not yet fully automatic.

In the following pages our authors attempt to show you what is already available, and what is now being developed to bring on the era of Optimized control. In addition, in 34 pages we have revised our 1952 Guide to Process Elements, in that way hoping to bring you in capsule form the whole broad picture of process instrumentation hardware as it stands today.

CALVIN S. CRONAN
STEVEN DANATOS
THEODORE R. OLIVE

Process Instrumentation in Transition 251

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Data Handling Systems 274

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Controllers and Final Control Elements 259

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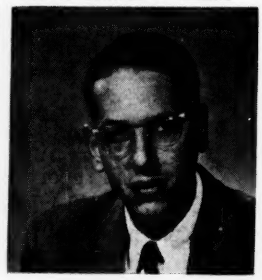
Computers in Process Control 280



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Where Primary Elements Are Headed 263

THEODORE R. OLIVE

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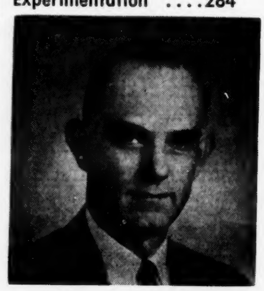
Control by Automatic Experimentation 284



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Control by Analytical Instrumentation 266

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Guide to Process Instruments Elements.287

STEVEN DANATOS

Danatos is Assistant Editor, Engineering Practice, *Chemical Engineering*. His 34-page guide section represents a revision of roughly 50% of the 1952 chart. In addition, it has been expanded 25% with new material. Danatos is a registered professional engineer in New Jersey. An ME and MS graduate of Stevens, Danatos was an ass't prof.

Chemical Process Instrumentation in Transition

Lloyd E. Slater*

Process control today is on a "maximized" plateau of high efficiency; but to go beyond this to tomorrow's "optimized" systems will mean a period of rigorous "introspection" and analysis, demanding the best efforts and cooperation of chemical and control engineers.

Today's automatically controlled chemical process plant is often hailed as "industry's most advanced stage of automation." Does this mean that automatic chemical processing has reached its pinnacle of efficiency—that adding more instrument and control technology would merely be gilding of the lily?

An emphatic denial from the growing legion of process control engineers would greet this question. "Heavens, no!" they would chime. "First of all, most of us have a long way to go before we get top efficiency in our present systems. When we do it, it will be time to take stock and start all over."

The fact is that perfection, to today's searching engineer, is no longer an end in itself—it is a barrier. When refinements and improvements reach a zenith, when the last bit of efficiency seems extracted from a given plant, then, says our engineer, there is some intangible barrier before us. The time for introspection and a completely new approach has come. Progress must be a never-ending road.

Three Stages in Progress

How will automatic chemical process control get beyond its present level of efficiency? To those deep in the work it appears that progress will come through three stages:

- **Maximization**—The concerted effort to increase the efficiency of existing processes by using the best instrument and control hardware and techniques.
- **Introspection** — The needed look inward into the dynamic characteristics of the process itself in order to progress beyond the stage of maximized environmental control.
- **Optimization** — Steps towards the highest degree of process efficiency through the synthesis of optimum new systems.

How far has "maximization" proceeded? One important gage is that most chemical firms now recognize the impact of automatic control technique on process efficiency and hence may allocate as much as 15 to 20% of new plant costs for instrumentation. But an even better indication is that a majority of the companies have also launched a clear program of maximization by—

1. Setting up autonomous instrument and control engineering groups that are able to specify hardware based on a specialized knowledge of the technology.
2. Forming instrument research and development groups that are able to design and build specific needed units which are not commercially available.

Establishing self-contained hardware development groups has inevitably led several of the larger chemical companies beyond the maximization concept. While initially preoccupied with developing better equipment for control of the process environment (i.e., flow, pressure, temperature, level, etc.), sooner or later these groups create the mechanized equivalent of laboratory analysis instruments, suitable for location directly in the process stream.

Subsequent attempts to tie such instruments into the automatic process control system—to "optimize" the process through an idealized "master" control of the product itself—reveal the magnitude of the problem. This activates still another specialist group within the firm: a group of chemical and control engineers assigned to dredge up the little-understood and long-neglected dynamic characteristics of process systems.

The transition of automatic chemical process control from maximized unit operations to optimized systems is thus already in progress in the pilot plants and laboratories of a few chemical firms and educational institutes. This article will explore the activity in each stage of the transition and show how all roads may lead one day to the con-

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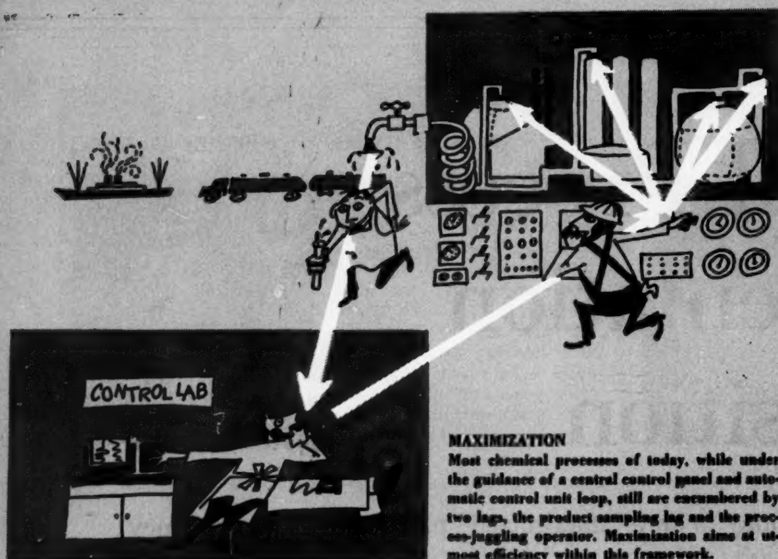
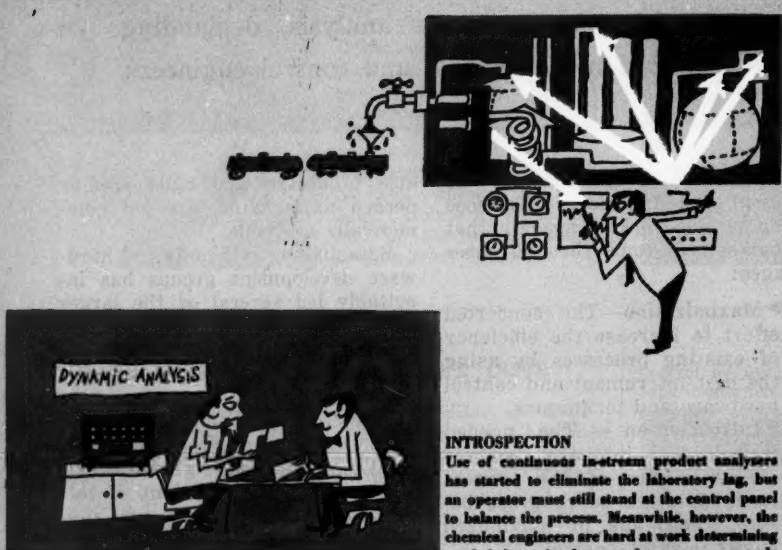
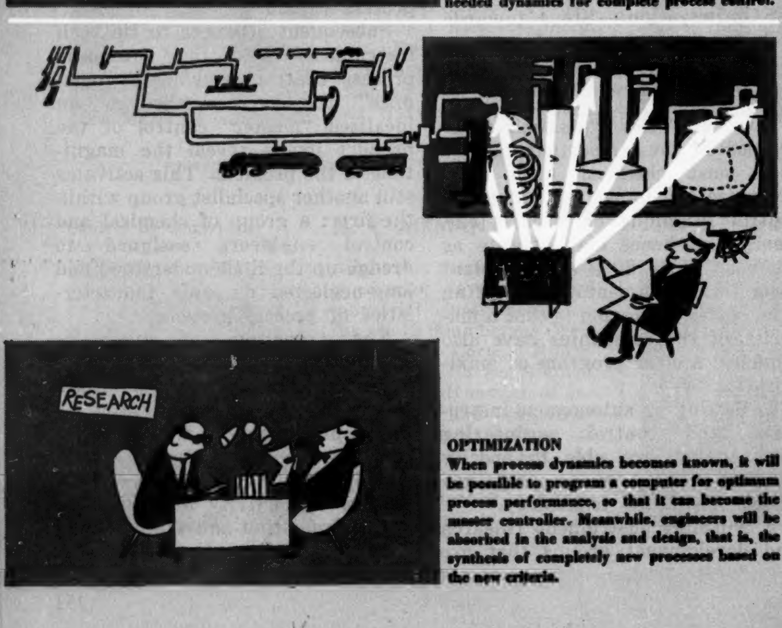


MAXIMIZATION
Most chemical processes of today, while under the guidance of a central control panel and automatic control unit loop, still are encumbered by two lags, the product sampling lag and the process-juggling operator. Maximization aims at utmost efficiency within this framework.



INTROSPECTION
Use of continuous in-stream product analysers has started to eliminate the laboratory lag, but an operator must still stand at the control panel to balance the process. Meanwhile, however, the chemical engineers are hard at work determining needed dynamics for complete process control.



OPTIMIZATION
When process dynamics becomes known, it will be possible to program a computer for optimum process performance, so that it can become the master controller. Meanwhile, engineers will be absorbed in the analysis and design, that is, the synthesis of completely new processes based on the new criteria.

trol engineer's Mecca: the truly automatic process.

MAXIMIZATION

Maximization has been defined as "a *concerted* effort to increase the efficiency of existing processes by using the *best* instrument and control hardware and *techniques*." The key words in this definition are "concerted," "best," and "techniques."

Only a few years ago most chemical firms bought and applied their instrumentation "after the fact." That is, a new plant would be designed, even built, before its measurement and control hardware was specified. Furthermore, the selection of instrumentation usually was done on a price basis and by purchasing people completely unfamiliar with the function of automatic control.

When a company formed an independent instrument and/or control engineering group, it was usually the first sign of a *concerted* effort towards maximization. At first this group would exercise its know-how and authority by selecting the *best* instruments and controls for a given installation—no matter the price or the vendor. Then, since proper control specification demanded an intimate knowledge of the process, the group ultimately got involved in design of new plant. At this point the *techniques* of the control engineer—his means for dealing with capacity, lag, dead time, etc., in the control loop—started to influence plant design.

In his concerted search for better equipment and techniques, today's process control engineer keeps lighting fires under the development departments of the instrument makers. Let's examine just three areas of hardware development that have been stimulated by maximization:

▶ **More Effective Measurement**—An urgent need for better flowmeters, new ways to meter solids, more specific units for composition and stream analysis.

▶ **More Speed, Precision**—Many users feel that their processes warrant more speed, sensitivity, and flexibility in measurement and control devices.

▶ **Better Actuators**—A demand for improved design and dynamic response characteristics to match actuators to vastly improved controllers.

More Effective Measurement

In a report to a recent meeting of the Philadelphia Section of the Instrument Society of America, John Johnston, Jr., of the Du Pont Co., told how his group, in studying a typical flow measuring system on a reactor, detected apparent errors often exceeding 20%. It took nearly two years, said Johnston, to track down the source of these errors and to narrow the over-all measurement error to within a needed ±3%.

The widespread conversion of batch to continuous operations, the shorter reaction times of subsequent processes, and the more critical ratios between ingredients has forced many control engineering groups into similar "agonizing reappraisals" of measuring techniques.

Perhaps the most closely studied measurement has been flow, since this variable inevitably grows in importance as processes become faster and more critical. Until recently, most chemical fluids have been metered by velocity-inferential devices, mainly of the flow-restriction, differential pressure type. While simple and effective in many installations, such metering is subject to numerous errors: it is affected by viscosity changes, pulsations, ambient temperature shifts, etc. In maximizing studies, these errors often prove enough to suggest drastic changes in long established flow measuring set-ups.

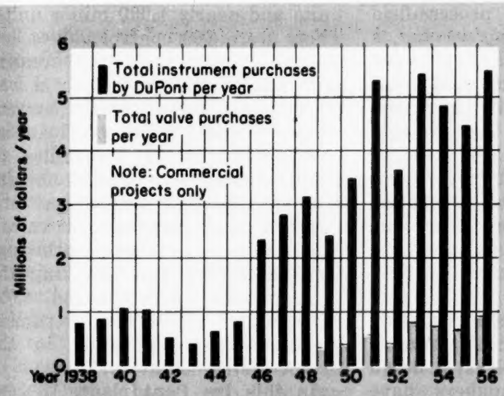
Two new approaches in velocity metering are now being experimented with that overcome many of these inherent errors. They are the turbine type flowmeter and the electromagnetic meter. Many of today's chemical reactions, however, involve extremes in temperature and fluids density which make even improved velocity flow measurement inadequate. Pioneer installations have thus been made with so-called mass flowmeters—units that meter by weight rather than velocity, from which volume is inferred. At least three true mass flowmeters became available in the past two years. Also, a few of the new velocity-volumetric types have been equipped with density compensation to yield mass flow.

Conversion from batch to continuous has also focused attention on the need for better ways to meter solids into processes. Until a few years ago most continuous dry feeders were of the volumetric, precalibrated type. By equipping these shaker, star, or vibrator feed devices with variable-speed drives it is possible to make flowing-solids control a rudimentary part of the automatic control system. However, a very few control installations were able to achieve better than ±3% feed error.

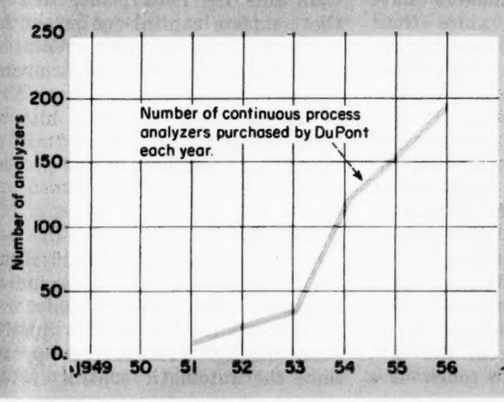
More accuracy in dry metering control has come through gravimetric feeders, where the material is continuously weighed—usually on a short weigh belt—as it enters the process. Considerable improvement in strain-gage and load-cell technique has narrowed the expected error in belt metering to within ±1%. Errors of less than one-half of 1% have been realized using another, more costly (roughly $6,000) type of gravimetric feeder: a loss-in-weight unit that continuously feeds from a scale-mounted hopper.

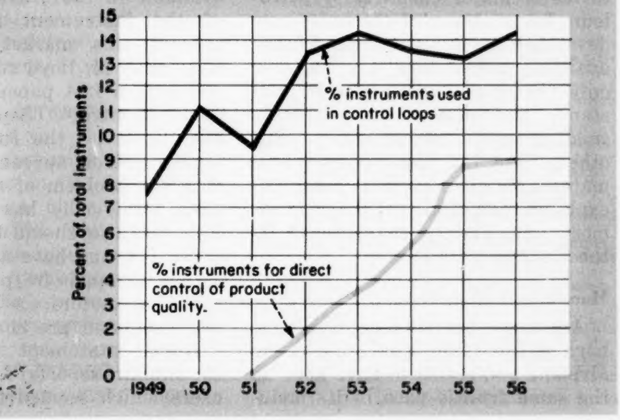
A New Measuring Tool

Studies of improved techniques for measuring liquids and solids have inevitably led the process control engineer into non-Newtonian



STATUS OF MAXIMIZATION
These graphs, provided by the engineering department of the Du Pont Co., offer some excellent clues to how fast Maximization is progressing in chemical process instrumentation. The graph at the left totals all of Du Pont's instrument purchases and compares them with the sizeable increase in control valve purchases since 1949. Growth of the latter is a sure sign that more instrumentation is becoming involved in automatic feedback control systems. The graph at left below shows the surprising number of in-stream analyzers that DuPont has put to work in the last five years. At right below it becomes clear that direct quality measurement has become a major preoccupation of control system designers.





flow. As chemical slurries and suspensions become more concentrated they exhibit peculiar nonlinear patterns in their flow behavior, and flow metering in itself becomes meaningless as a process control. The isolation of rheological data—usually by specialized viscometers and elastometers—has become a major project in many process control laboratories.

Aside from clarifying peculiar behavior in flow, rheological instrumentation is opening up a completely new field in finished product measurement. Quality standards for viscous products such as paints, lubricating oils, and cosmetics involve "blanket" measurements of viscosity or flow. But what really is needed, say the rheologists, is a single-dimensional assay of some rheological property such as thixotropy (work softening) or yield value. In many cases these rheological measurements are now being made continuously on-stream and have strongly influenced the design of the process and its control system.

The process control engineer's success with in-stream closed-loop control of single-valued product characteristics (i.e., pH, density, viscosity, rheological qualities) has directed his interest towards more complex stream quality measurements. Why not, he asks, develop the in-plant equivalent of the bench analyses which are the real arbiters of operating procedure? Think of the time for sampling and laboratory procedures that will be saved, and the reduction in off-quality product.

To meet this challenge a whole new segment of the instrument industry has sprung up in the past five years to produce stream analyzers. Almost all of the new stream analyzers originated in the instrument development laboratories of major chemical or petroleum firms. Many of the units now developed are still not commercially available since they are suitable only for measuring a specific substance and limited to a specific small range of concentration. But others, like the vapor-phase chromatograph have such a wide, unexploited potential that they are almost immediately snapped up by the instrument makers.

More Speed, Precision

Automatic control equipment was born at about the same time as the airplane and seems to have kept up the same frantic pace in its metamorphosis. World War II, for example, brought jet transport and guided missiles, but it also produced servomechanisms and vacuum-tube instrumentation.

While the process field has not used the precision servos of fire control as such, there is no doubt that compact servo designs influenced the appearance and function of the miniaturized industrial controllers which came in when graphic panels hit the process field. It was tacitly understood, however, that the precision of military servos was unneeded in controllers that were to be coupled with the mechanical measuring and transmission systems in the usual process-control loop.

Vacuum-tube instrumentation, on the other hand, is the center of a definite design controversy in the process field. Many of the "maximizing" engineers claim that electronic controllers coupled with electric transducers open up new possibilities in faster, more precise and certainly more flexible measurement and control. But others feel that sensitive electronic units are "trimming the cake"; that, properly used, the rugged, proven mechanical systems more than hold their own.

At this date it appears that electronics is bound to triumph. A recent survey of its process-field readers by *Control Engineering*, a McGraw-Hill magazine, revealed that over 90% already had some electronic equipment in their control systems and that the rest plan to use the technique soon. Reasons advanced for use: better sensitivity and speed of response, cheaper transmission, improved set-point control.

Better Actuators

The first all-electronic miniaturized control equipment became available in 1951; at least a dozen of the instrument makers have entered this market since then. But, as D. M. Boyd reported in his well-known ISA paper, "Why Electronic Control" (Sept. 1954, No. 54-9-2), ". . . the future of electronic controls appears very bright once the problem of operating the valve electrically has been solved. This actuator should be simple, inexpensive, and have a performance at least equal to pneumatic diaphragm motors as far as speed and deadband are concerned."

Boyd's statement was followed by similar reports from the first users which seemed to touch off a flurry of actuator developments. In 1955 a most promising approach appeared: an electro-hydraulic type actuator in which the control signal operates a self-contained pump and accumulator to supply thrust power on a conventional valve stem. At the Instrument-Automation Show in 1956, three new electro-hydraulic actuators were shown, as well as an all-electric unit with excellent operating characteristics—a 4-in. per min. stroke at 500 lb. thrust. In the *Control Engineering* survey (Nov. 1956) over half the electronic system users were also equipped with electro-hydraulic actuators.

What Price Efficiency?

As control equipment and techniques improve, as the complexity of systems grows and efficiency gains narrow down to fine details, even enthusiastic "maximizers" stop taking for granted the value of improvements vs. their cost.

John Johnston, Jr., of Du Pont, outlined the problem in a recent speech, "That there is need for simplifying the operation of a chemical plant is clearly evident. At one of our newer installations, a moderate-sized chemical plant costing $8.5 million, $1.4 million was used for instruments. These consisted of more than 1,000 major units and nearly 1,000 minor units. There were 300 control valves and over 15 highly specialized analyzers. The central control room was of graphic design using conventional pneumatic control almost exclusively. Nearly 50 miles of copper tubing was needed for interconnection between transmitters, control room and control valves. More than 60 engineering drawings were necessary for installing the instruments. We expended 4,000 man-hr. in training the instrument mechanics and operators in the use of instrumentation."

In this Du Pont plant, 18% of the complete capital equipment investment is in its instrumentation and control; in other high-temperature and hazardous processes, this investment may run up as high as 30%. Clearly, the control "tail" is almost starting to wag the process "dog."

Next Step to Progress?

Oddly enough, the latest result of the quest for the "maximized process"—the in-stream analyzer—is one of the easiest to justify economically. Prior to its appearance the automatic control system

tried to preserve the ideal material balance at various process steps by regulating secondary parameters such as flow, temperature, pressure, etc. Continuously available information on product quality, however, now enables the operator to juggle and reset controls in several interrelated systems, if necessary, to produce optimum product. W. C. Gardner, of C. F. Braun has described how a $10,000 mass spectrometer in a sulfur plant improved operating efficiency by 3% through this kind of operator feedback.

The technique of operator feedback through readings from a stream analyzer has suggested a logical break-through to the control engineer: the integration of a number of unit controls into a "master" control system based on end-point or product measurement. Instead of the operator, why not tie in a computer programmed with operator logic?

At this point—with a tantalizing glimpse of the truly automatic process just ahead of him—our control engineer comes to a grinding halt. For not only is the process operator unable to tell him quantitatively why he does certain things to integrate a production process, but the literature of chemical processing is also notably barren on this subject of process plant dynamics.

A New Collaboration

Up to the present, most progress in the automatic operation of chemical processes has come from the instrument and control engineer. But it is now obvious that a new stage has been reached where the fundamental job of analyzing and evaluating the performance of the process itself must be done by his necessary collaborator, the chemical engineer. With this work behind him, the chemical engineer will be able to supply his control colleague with precise information on plant behavior under given conditions and the present blind spots in computer programming will be eliminated.

Collaboration between chemical and control engineers, aimed at closing the gap with dynamic analysis, has proceeded with success in a few isolated and limited cases. But the mere fact that it is proceeding is a sure sign that process control is already launched into its stage of Introspection.

INTROSPECTION

The stage of Introspection in the transition of chemical process control is defined as "the needed look inward into the *dynamic characteristics* of the process itself in order to progress beyond the stage of maximum environmental control." The key words in this definition—the words that justify a new collaboration between control and chemical engineers—are obviously "dynamic characteristics."

Why dynamic characteristics? In the past the conventional design of a chemical plant and its control system was based on data accumulated by chemical engineers on the balanced or steady-state characteristics of the component steps, such as heat exchange, mixing, distillation, etc. Unfortunately, in actual production these characteristics, or controllable quantities, are usually changing continuously. Yet it is the function of the "static design" control system to maintain fixed values of the controlled variables, and to do so despite the ordinary process load changes. Such disturbances can, and usually do, cause wide swings in process equilibrium and subsequent changes in product quality. It is obvious that the truly optimized plant and its control system must be based on dynamic rather than static fundamentals.

Dynamic Analysis—a Challenge

Today very few quantitative facts are available on the dynamic characteristics of process plant. Filling this gap offers a great challenge to the chemical engineer; it not only opens the way for the collaborating control engineer to optimize design in his control systems, but also suggests the synthesis of completely new or improved processes from the knowledge gained.

Expressed differently, dynamic analysis gives the chemical engineer the opportunity for fundamental studies in the dynamics of unit operations, quite apart from automatic control. There is a good chance that the subsequent gain in the dynamic performance of the process may be even more valuable than the improvement in automatic control technique, owing to acceleration of throughput or reduction in energy consumption.

How Far Have We Come?

Dynamic analysis got its start well before World War II. Most of this early work, however, was aimed at exploring the behavior of feedback control systems and equipment by mathematical techniques. One of the rare published works on the analysis of process plant was that of C. E. Mason and G. A. Philbrick (*Transactions ASME*, 1941): a complete systems analysis of a series of surge vessels. The Mason-Philbrick technique was later used to control flow between columns in petroleum fractionation trains.

World War II unleashed some powerful new tools for dynamic analysis. The scientist-engineers developing servomechanisms for weapons control systems borrowed techniques from electrical network and feedback amplifier theory and came up with the control block diagram, the equivalent circuit, and the frequency response plot. But, more important, they applied these tools not only in the analysis of complete systems, but in the *synthesis* of new, optimized control systems.

It took a few post-war years for the implications of servomechanism theory and technique to reach the chemical process field. But since 1948 the signs of such work in this field have grown in volume and purity. A few samples are listed in the tabulation:

A Few Steps in Servo Theory's Invasion of the Process Field

1950: C. I. Rutherford, in England, introduced frequency response technique to process and plant analysis (*Proc. Inst. Mech. Engrs.*, London, 1950).

1951: D. W. St. Clair, W. F. Coombs (Eastman Kodak) and W. D. Owens (Minneapolis-Honeywell) described use of frequency response for automatic control system analysis at ASME annual meeting (see Paper 51-A-127).

1952: Y. Takahashi, Japan, discussed his method of analyzing heat exchange processes by the transfer function at Cranfield Conference in England (see later description, *Control Eng.*, May 1956).

1953: F. W. Velguth and R. C. Anderson (Corn Products) detailed an analytical method for determining minimum capacities for control applications at annual ISA meeting (see ISA Paper 55-6-3).

1953: A. R. Aikman, then in England at ICI Ltd., reported using frequency response technique on a spray dryer and heat exchanger, before International Conference on Frequency Response held by ASME in New York (see "Frequency Response," McMillan Co., New York).

1954: N. Ream, England, told the annual meeting of the Society for Instrument Technology how to secure process control settings from frequency characteristics (see *SIT Trans.*, Vol. 6, 1954).

1954: J. B. Reswick (MIT) published his doctoral thesis on a method for dynamic process analysis without upset (see later description, *Control Eng.*, June 1955).

1954: J. M. L. Janssen (Royal Dutch Shell

Lab, Holland) reported a method for studying control system behavior by means of deviation ratio (more completely described in *Control Eng.*, Nov., Dec. 1955).

1955: E. Holzman (Shell Development) described work on the dynamic analysis of autothermic chemical processes before ASME (see Paper 55-IRD-5).

1955: P. Buckley (Du Pont) covered work on the dynamics of pneumatic control systems at annual ISA meeting in Los Angeles.

1955: H. Vooter (Royal Dutch Shell, Holland) told of application of frequency response technique to a distillation column at joint meeting of BIChE and SIT at Cambridge, England.

1955: A. M. Mozley (Du Pont) offered data on predicting the dynamics of a concentric heat exchanger to ACS meeting, December 1955.

1956: At fall ISA meeting in New York, chemical process control engineers reported on: (1) using an analog computer to study process dynamics; (2) frequency response tests on a fractionating column; (3) dynamic analysis of a chemical reactor; (4) dynamic analysis of a heat exchanger.

By the end of 1956, the tempo of work in dynamic process analysis reached a new pitch when the newly formed Process Control Subcommittee of AIChE conducted a round-table discussion on the subject in its December 9-12 meeting in Boston. In reviewing the more than two dozen papers on various aspects of chemical process dynamics of the past three years, this committee found a wealth of techniques to use in the forthcoming era of introspection and analysis.

As *Control Engineering's* February 1956 editorial stated it, "From this springboard the 'chemicals' can rise to their needs if they publish their experience, include control engineering in chemical engineering curricula, and cooperate with other professional groups . . ."

What are the "tools" for chemical-process introspection? Our brief review has listed them and hinted at the degree of their present use in the chemical field. They are—

1. Step upsets coupled with mathematical analysis
2. Frequency response analysis
3. Statistical techniques
4. Analog computer simulation.

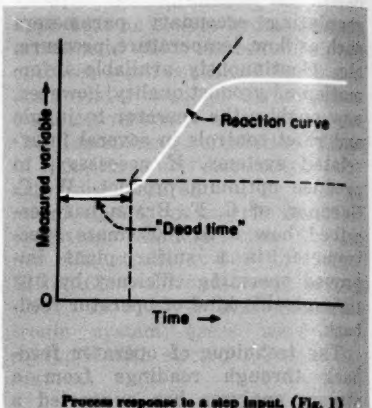
Dynamic characteristics of process plant and control systems—the object of introspective probing—are simply the time response of each system and its members to a change in energy supply and load. Hence a tool for studying dynamics may be any form of experimental technique that will assay the response of a plant and its controls to such quantitative changes.

Tools for Introspection

Transient Response—The response of a process or a control system to a step change in its input, or an abrupt "upset," is known as its transient response. The graph in Fig. 1 illustrates the effect of this change on a process. After a certain dead time, the measured variable which has been upset will move to a new level—the steepness of its reaction curve being a good measure of process capacity. To study system dynamics various step inputs are applied and resultant data are mathematically converted to numbers which characterize the system's response and its controllability. The technique becomes cumbersome in analyzing complex systems, but has been used widely to derive controller settings.

Frequency Response—In recent years, the frequency response technique has been more widely used to study process dynamics because of its easy application and relatively simple corollary mathematics. As Fig. 2 shows, instead of a step input disturbance a continuous sinusoidal input disturbance is imposed on the system, resulting in a sinusoidal output. The output usually varies in amplitude and phase from the input, the magnitude of these changes depending on the system properties or dynamics. The frequency response is usually determined over a wide range of frequencies and the resulting curves are analyzed graphically by means of a Bode or logarithmic plot to determine the system's dynamic response to load changes, that is, its transfer function.

Statistical Technique—Both transient and frequency response analysis of process plant, however, have one shortcoming: they subject the process to an upset which may reflect itself in lost or off-grade product. A recently developed technique of statistical correlation circumvents this problem. In this approach (Fig. 3) a random noise signal is imposed on the normal signal input. Accurate high-speed normal operating records are made for related input and output functions in the system (i.e., valve stem position on steam to the heater, and product temperature). The input record is auto-correlated and the output record cross-correlated against input, and both are fed into an analoging device—Reswick's delay line synthesizer (see *Control Engineering*, June 1955, p. 55)—which resolves what essentially is the transfer function of the system in the form of an output voltage that can be displayed on an oscilloscope.



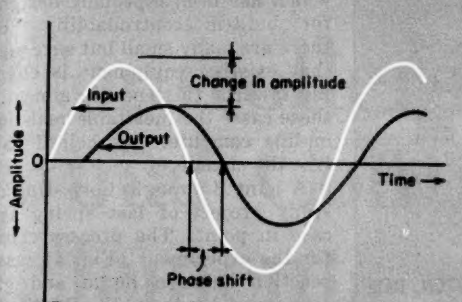
Process response to a step input. (Fig. 1)

In Reswick's delay line synthesizer we come extremely close to still another tool for process analysis: the electronic computer. As information on the dynamic characteristics of a system is gathered it becomes more and more possible to assemble the hardware for its mathematical model or analog. This computer can then be "turned inward" to study the dynamic response of the simulated system to different types of disturbances. It can also be used to find automatic start-up methods and test the performance of new control components before they are installed.

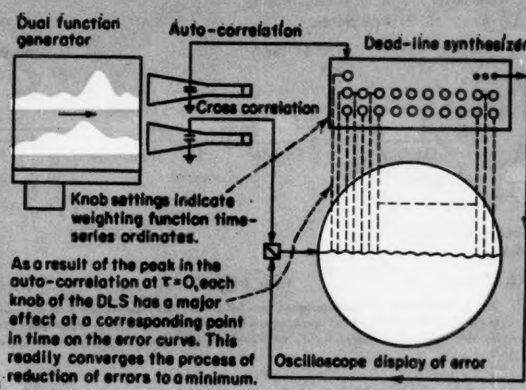
When an analog or digital computer reaches the stage where it completely simulates the dynamic characteristics of a system then, of course, it ceases to be simply an analytical tool and can become a true optimizing automatic controller. But more about this later . . . there is still another step in between.

Getting the Data

In one way control hardware's evolution is like the primeval eel. The eel grew legs to crawl out of its drying lake bed; both seem to anticipate future needs. The current preoccupation of the process field with data logging is a case in point. While a few dozen extensive logging systems are already working in chemical plants and many more are planned, few process control engineers can really tell you why they are buying their equipment. Yet like the eel's dry lake bed, the process control field's need will soon be here and the field seems almost instinctively to be taking the steps to meet it.



Process response to a sinusoidal input. (Fig. 2)



Study-sans-upset, via Reswick's synthesizer. (Fig. 3)

The fact is that as the tools and techniques for process analysis become more and more like a computer, the need for gathering and providing process information to the computer in proper form becomes more and more urgent. Data logging systems have introduced the needed analog-to-digital converters, the needed linearization and shaping of scale factors that will link the hardware of the automatic industrial control system of today to the computer-controllers of tomorrow.

A solid belief in this "look ahead" function of data logging is already here. A recent survey of process control readers by *Control Engineering* (Jan. 1956, page 59) asked them to rate the nine most common justifications for a logging installation. Out of the welter of labor-saving reasons came this winner: "to provide information for process plant research and analysis." Fully 375 out of 532 process control engineers with data logging experience advanced this reason as a major justification.

OPTIMIZATION

The process control engineer's ultimate objective, the stage of Optimization, is defined as "steps towards the highest degree of process efficiency through the *synthesis* of optimum new systems." The key word in this definition is, of course, "synthesis," the word that makes "optimization" a unique new level in progress. To Webster's definition of synthesis we might add a single word: "the combination of separate elements into an *optimum* whole." In the case of process control, synthesis describes the melding of automatic technique, or controllability, with process design to secure an optimized plant or system. Thus synthesis implies the quantitative incorporation of instrumentation at the design stage.

How will optimum system synthesis come about? Let us return briefly to the "tools of Introspection" and their purpose. The collecting of dynamic response data on unit operations and control hardware offers the collaborating process designer and control engineer criteria for selecting the proper response characteristics in both control and process equipment. In attempting to integrate these criteria into a system there will obviously be give-and-take. Various concessions to adapt the result to an optimum balance between economics and performance will be needed. But there will also surely be a synthesis of completely new designs in the process.

The Optimizing Method

The method for synthesizing optimum new systems is known formally as "control systems engineering." A classic definition (*Control Engineering*, September 1956) describes control systems engineering as three basic steps:

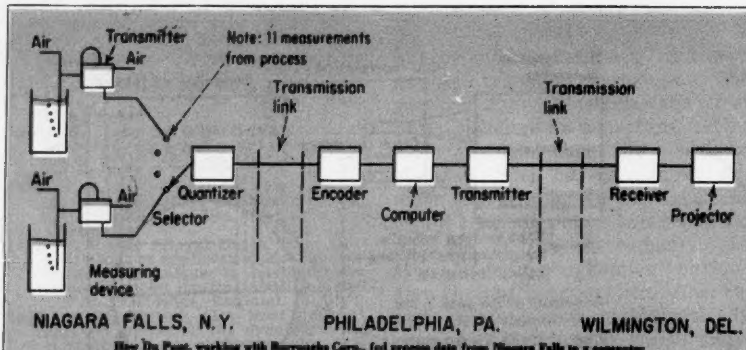
1. *Specification* — Knowledge of process and equipment dynamics is merged to set up the performance criteria for the desired system.
2. *Synthesizing*—The system is created on breadboard, mathematically, or by analog to analyze its adherence to performance criteria.
3. *Evaluating* — The synthesized system is projected to its commercial form and subjected to the test of practical economics.

Before prototype or actual new system is ever built, control systems engineering subjects its design to a thorough, iterative procedure that has one end in view: the optimized system, or a plant which produces maximum specified product at minimum cost.

Role of the Computer

In the previous discussion we also hinted at another route to optimization: the electronic computer as a "master controller" that would absorb product quality measurements and other variables and automatically control the plant at optimum level. Today the human operator, with only his intuitive knowledge of process dynamics, attempts this formidable optimizing job. But even if we assumed that the operator had valid data available on dynamics, his ability to optimize would still be inherently curbed by his slow capacity to receive and interpret large masses of data; his frequent need to perform long and involved computations; and the large number of variables which preclude advance programming.

The proposal, therefore, is that a computer be substituted for the human operator to overcome operator lag and inadequacies by automatically—and in split seconds—determining the proper relationships among the process variables for optimum process performance. To do so, the computer must be realistically supplied with the necessary equations based on the



How Du Pont, working with Burroughs Corp., fed process data from Niagara Falls to a computer in Philadelphia which supplied operating and management information to Wilmington. (Fig. 4)

dynamic characteristics of the process.

How will the computer control? It is suggested that the computer must become an integral part of the process instrumentation and communicate with the process directly. The "integration" would take place this way:

1. Measuring elements would transmit information describing the present state of the process to the computer.

2. The computer would then solve the equations which define optimum process performance.

3. The completed results would next be transmitted to control devices to manipulate the process variables to desired values.

4. Actual process behavior would then be compared with that predicted by the computer and the parameters of the equations adjusted to a realistic optimum.

An Optimizing Experiment

This description of how a computer can control a process is essentially the method followed in a research project under Prof. Donald P. Eckman's direction at Case Institute of Technology. For three years a team of graduate students studied the kinetics of the chemical reaction inside a batch reactor for hydrogenating vegetable oils. Having expressed the data analytically in the form of differential equations, the important factors affecting the kinetics were pinpointed. Pressure and temperature were found to be the most important variables affecting process performance.

Using the calculus of variations methods, the Case researchers next derived a complete set of new equations to define an optimum path for the process, that is, a time program of operating conditions which would yield the specified product with minimum processing time. A great deal of detailed work was done to compare product composition in pilot runs to calculated values. Values for the samples were fed into a computer which applied them to the solution of the optimizing equations. Thus, each time a sample was taken, a new optimizing path was defined based on the most recent process information available.

At this stage, by using a rapid method for product composition analysis that they had developed and by eliminating error accumulation, the Case research team had essentially set up a semicontinuous type of computer control. From an academic standpoint, computer process control was now a proven venture.

Case Institute considers its successful demonstration "exploratory work" and hopes to continue the project, substituting a digital computer for the analog first used. Eventually they hope to apply the method to a complete continuous process. But Eckman and his associates see the practical application of their findings as "years ahead."

Computers and Systems Engineering

While the Case experiment proves the possibility of a computer control, it confines the demonstration of optimization to an existing process. Whether computer control is used or not, the purist control-systems engineer sees the ultimate objective as optimization through the synthesis of new and improved processes. Why be bound by the tradition of existing processes, he asks?

Almost nothing has been published about process equipment which has been especially designed for built-in controllability. But there are many small but sure signs that existing equipment is changing towards this end. In almost all these cases the inevitable real-time, on-line computer has helped catalyze the change.

A joint Burroughs Corp.-Du Pont study project of last spring is a case in point. The process chosen for the experiment (Fig. 4) was a reaction between liquid and gaseous ingredients in Du Pont's Niagara Falls plant. Eleven measurements—ten level and one composition—were picked up, converted to electrical pulses and sent by telephone wire to the Burroughs Computer Center in Philadelphia. Here the signals were encoded and fed into a general-purpose digital computer which had been programmed with a certain amount of process dynamics, and which was set up to calculate transfer, yield, averaged production, and loss figures at intervals frequent enough for rapid evaluation of process behavior. These figures were flashed on a screen before a management group in Wilmington.

While the Du Pont-Burroughs experiment clearly demonstrated the utility of on-line computation for management and operator guidance of the process, several significant hurdles in the path of ultimate computer process control were taken:

1. The computer was hooked up to existing industrial measurement equipment and the analog-to-digital conversion was simple and inexpensive.

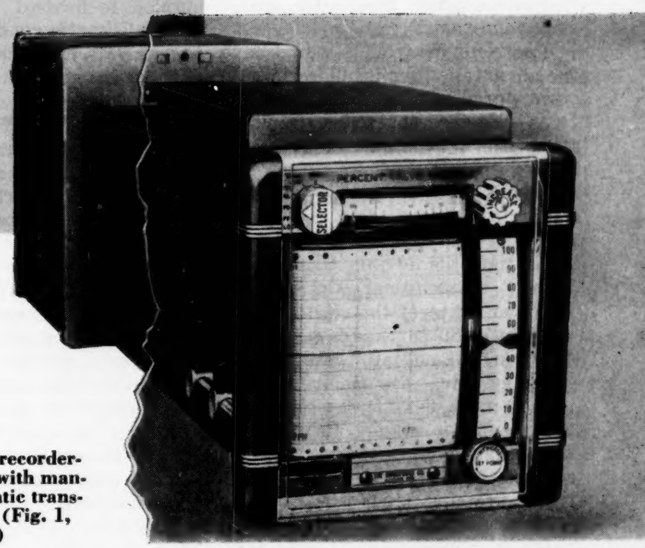
2. The computer was programmed, at least in part, to the dynamics of the operating process —hence was more than just a data-processing machine.

3. The rapidly obtained and revealing data on process performance provided by the computer suggested some spot improvements in the operating process and its control.

So, it appears that progress into the era of the synthesized process and computer-controlled plant—the stage of Optimization—is coming through short, practical steps, as well as through basic demonstrations of the principles involved. That the path ahead is thorny and tedious, no one questions. But there is also an emphatic din from a growing legion that claims it is the proper, if not the only route to travel.

Controllers and Final Control Elements

Werner G. Holzbock
Askania Regulator Co.



Electronic recorder-controller with manual-automatic transfer switch. (Fig. 1, Swartwout)

During the past five years the outstanding development in controllers and final control elements has been the spreading use of electronic control systems.

Electronic Vs. Pneumatic

Comparative merits of pneumatic vs. electronic control systems have been discussed widely. Mainly, discussion has centered on:

- Cost of installations.
- Frequency of trouble and maintenance.
- Speed and quality of controller response.
- Flexibility.
- Final control element.

Installation Cost—No generally valid data are available. If you don't consider the interconnecting lines, a pneumatic system usually costs less. Where signals must travel 500 ft. or more, electronic systems generally cost less to install.

Long transmission lines occur most often as the links to centralized control panels. That is why electronic control systems and miniaturization went hand in hand, since both are particularly suited for centralized panels.

For explosion-proof service, cost may favor the pneumatic system, although under centralized operation only the primary and final control elements generally require explosion-proof consideration.

Trouble and Maintenance — So far, electronic control systems now operating seem to be remarkably free of trouble. And they are at least as safe as pneumatic systems.

Tubes need out-of-schedule replacement much less frequently than is generally assumed. Only minimum amounts of trouble-shooting effort and time are needed to carry out replacements.

Instrument men may need some re-education to handle this type of system. Some of the resistance to use of electronic controls is based on the alleged difficulty of re-education.

However, this resistance is more psychological than factual. The objection disappears when the electronic control system turns in some clear-cut advantages. An example of such advantage is that shown by the electronic potentiometer measuring instrument. For given applications, its advantages are so obvious that people hardly ever object to using it.

A more serious disadvantage, however, is loss of electronic control when power fails and a supply of stand-by power is not available. By contrast, an air compressor system generally has sufficient reserve capacity to carry over a short-term power failure.

Climatic conditions may put the pneumatic system at a disadvantage. In cold weather, air pressure lines may freeze, despite desiccation. Electronic control systems are free from such complications, provided they do not depend on compressed air to operate valves.

Response Speed and Quality—Stress on response has its origin in highly specialized servo theory. It has been carried into the process field without sufficient critical judgment.

Occasionally, high response speeds are certainly needed. But frequently, the demand reflects an expensive urge for perfection that is not needed.

The electronic controller may be faster than the pneumatic, particularly where there are long trans-

mission lines. However, this is an advantage only in exceptional cases. Time constants in chemical processes and final control elements practically always are considerably larger than the time constant even of a slow controller.

Quite possibly some people may be correct when they claim that motion lost within the mechanisms of pneumatic controllers suffices to introduce a significant dead band in the controller response. Thus, a wider proportional band is required to avoid instability under such conditions.

Electronic controllers would have the advantage then of allowing narrower proportional bands. Deviations of the controlled variable from the set point are corrected faster, thereby reducing the magnitude of the deviation.

Flexibility — Either the pneumatic or the electronic controller can satisfy the flexibility demanded by the conventional control loop. However, to meet the requirements of data reduction and computing functions — adding, multiplying, squaring, etc.—the electronic system is more flexible, by far, than the pneumatic system. It is in the light of such developments that you can see the decisive future for electronic systems.

Final Control Elements — This question merits separate consideration. Here, we can say that it does not decisively influence the comparison between pneumatic and electronic control systems.

Advantage Not Decisive—When you have sifted all the written and verbal comparisons between pneumatic and electronic systems, you conclude that neither system has a decisive advantage over the other.

In non-centralized systems, instrument people generally favor the pneumatic approach. On other installations, individual cost factors must be considered. Frequently, minor considerations or individual preferences may determine choice.

In any event, these are important points to consider:

- Requirements for explosion-proof equipment.
- Re-education of instrument men.
- Consequences of power failure.
- Climatic conditions.
- Data reduction and computing requirements.

Electronic Controllers

Two leading manufacturers of electronic control systems recently have made important changes in their devices. These changes are significant in terms of past, present and future developments.

Unitized Controller—Panel spaces used for mounting either the miniaturized pneumatic recorder or the electronic recorder are equivalent. However, while pneumatic controllers frequently are designed to plug into the back of the recorder, the electronic controller requires additional panel space in many cases.

Admittedly, the pneumatic arrangement saves panel space, but the controller cannot be adjusted from the front of the panel. You cannot observe how the recorder acts while you adjust the controller, except for set-point adjustments.

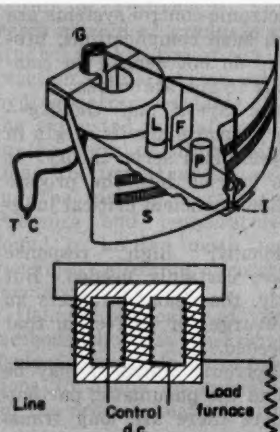
On the other hand, the additional panel space occupied by the electronic controller appeared worthwhile because it was more accessible and you could observe the record while making adjustments. Despite this advantage for panel mounting of the controller, at least one electronic manufacturer has changed over to a back-mounted controller similar to pneumatic equipment.

Somewhat the same difference has existed between electronic and pneumatic types with regard to the manual-automatic transfer switch. In electronic controllers this switch has been treated as a separate unit; miniaturized pneumatic controllers have the switch built into the recorder so that the recorder cannot be taken out without removing the manual-automatic switch, too.

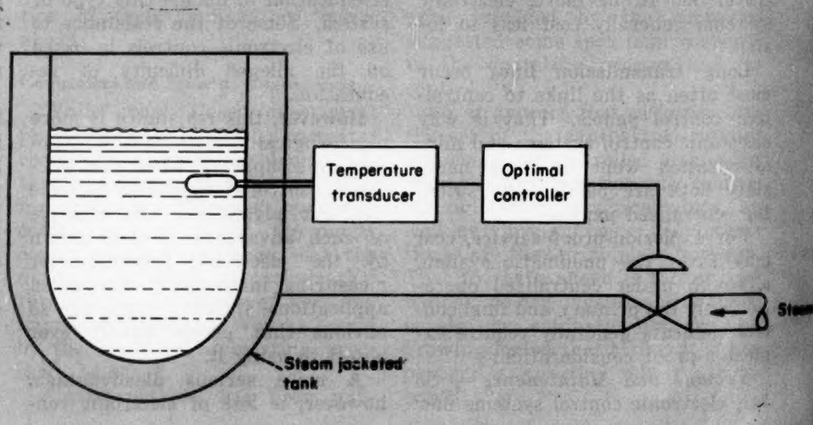
Now, however, the same electronic controller which mounts into the back of the recorder incorporates the manual-automatic switch as an integral part of the same unit, Fig. 1. Yet, both recorder and controller can be removed without disturbing the switch.

Transistors—From data reported by D. E. Barnes (Barnes, D. E., "A Review of Transistor Reliability," *Bureau of Ships Journal*, Nov. 1956, p. 28.) on the frequency with which vacuum tubes and transistors fail in telephone and computer usage, we can conclude that 0.1-1.0% of vacuum tubes and 0.1-0.6% of transistors fail per 1,000 hr. of operation.

While these results show longer life expectancy for transistors, the advantage is not so overwhelming as assumed occasionally. Transistors still cost more than vacuum tubes and tend to drift with temperature changes. Usually, this drift can be compensated for in the circuit, provided that surrounding temperatures do not exceed certain maxima at which the transistor becomes inoperative.



Controller and magnetic amplifier regulate furnace. (West Instrument, Fig. 2)



Optimal control regulates steam to tank. (Quaric Controls, Fig. 3a)

One controller now available is largely transistorized. One vacuum tube remains. The longer life expectancy gained by substituting transistors for vacuum tubes should prove to be an advantage for this design.

Magnetic Amplifiers — Probably cost is the only reason why magnetic amplifiers seldom have been used for industrial control systems. Certainly, their slightly poorer dynamic performance compared with electronic systems is hardly a factor. For ruggedness and life expectancy, they are superior to most any other system.

One application where the magnetic amplifier is used with considerable advantage is in regulation of power to a temperature-controlled electrically heated furnace, Fig. 2.

Galvanometer movement *G* is actuated by the emf. generated by the thermocouple *TC*. A manually operated setting arm that carries the setpoint indicator *I* may be positioned at any desired point.

On the setting arm, behind the scale, are a small light source *L* and a photocell *P* arranged so that light from the source is projected upon the photocell. As the temperature rises toward the point where the galvanometer pointer approaches the position of the setpoint indicator, the opaque flag *F* begins to interrupt the light beam.

Current passing through the photocell is reduced gradually until the flag reaches the point where the light beam is eclipsed completely. Thus, flow of current varies directly with the light intercepted by the photocell in accordance with the rise and fall of temperature at the thermocouple.

Current from the photocell is amplified by a vacuum tube and fed into the d.c. control winding of the magnetic amplifier. Variations in this control current modulate the current passing through the outer windings of the amplifier. Thus, electric power supplied to the furnace load is proportional to the variations emitted by the photocell.

Optimal Control—An electronic controller introduced recently is basically different from the conventional type. Instead of holding a variable at a predetermined set point or adjusting the set point automatically in proportion to some other variable source, it maintains the slope at which the controlled variable responds to changes in some other variable, Fig. 3a.

In the sketch, you see a process tank heated by steam. The relation between temperature and steam flow is not a linear one. Since the process is self-regulating, temperature rise slows down as steam flow increases.

Optimum control would occur at the knee of the curve, Fig. 3b, for tank temperature vs. steam flow. However, this curve is valid for only one steam temperature. If the steam temperature rises, a different condition exists as shown on the set of curves, Fig. 3c. Then the set point of the controller would have to be changed.

This may be done by a ratio controller, but only if a linear relationship exists between steam temperature and optimum tank temperature. Otherwise, the optimal control which controls automatically at the optimum slope of the curve (for the most economical tank temperature) may offer decisive advantages.

Final Control Elements

Wider acceptance of electronic controls has brought about some entirely new concepts of final control elements. Methods used today with electronic controllers comprise basically three approaches:

- All-electric actuators.
- Diaphragm-and-spring valves with electropneumatic relays.
- Electrohydraulic actuators.

Moving Coil—Most of these devices have one element in common, the moving coil. In principle it is shown in Fig. 4.

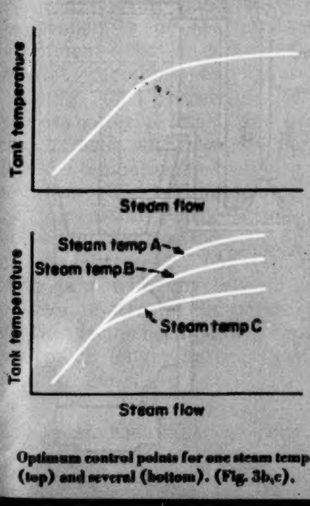
Coil is suspended in the air gap of a permanent magnet. Current flowing through the coil results in a force which repels or attracts, depending on direction of current.

If the force attracts, the coil will move into the air gap, expanding the spring from which it is suspended. When the spring force equals the signal force of the coil, the coil balances at this point.

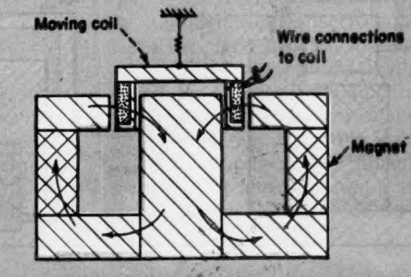
All-Electric Actuator—In one typical design of this element, the force of the moving coil is balanced by a feedback spring which is expanded by the motion of the valve stem. Any change of signal from the controller results in a new force level in the moving coil.

The resulting motion displaces the core of a differential transformer. Output from the transformer is fed into an electronic amplifier which energizes a reversible motor. The motor drives the valve through gears until the feedback spring again balances the input signal and steady conditions are re-established.

Stroking speed of this unit is 4 in./min. at 500 lb. max. thrust and 8 in./min. at correspondingly lower thrust. This is slower than



Optimum control points for one steam temp. (top) and several (bottom). (Fig. 3b,c).



Most electronic final control elements use moving coil. (Fig. 4)

most pneumatic diaphragm-and-spring valves. Thrust is about the same, if not slightly higher.

Electropneumatic Relay — Electrical output from a controller can be converted into a pneumatic signal by an electropneumatic relay. In turn, this signal is applied to a conventional diaphragm-and-spring valve, with or without positioner.

The principle of a typical relay is illustrated in the accompanying sketch, Fig. 5. Again, a moving coil is sensing element of unit.

On the right, the lever is fastened to a feedback diaphragm. When the electrical input signal increases, the resulting increase in force in the moving coil tends to move lever away from magnet.

This depresses the feedback diaphragm. Its downward motion displaces the pilot valve stem, opening the lower port. The result is that the air pressure increases under the feedback diaphragm as well as under the booster relay diaphragm.

The pilot valve remains open to the air supply until the pressure under the feedback diaphragm has increased sufficiently to balance the force due to the electrical input.

Increased air pressure under the booster relay diaphragm moves the booster valve stem upward and opens the upper port of this valve. Supply air then flows through the port, increasing the loading pressure and the pressure on the upper side of the booster relay diaphragm.

The upper port of the booster valve closes as soon as the pressures on both sides of the diaphragm are equal. This re-establishes balanced conditions, but at a loading pressure raised in proportion with the increased electrical signal.

Similar action takes place on decreasing electrical signals. In either case, the loading pressure follows changes in input signal in linear fashion.

Electrohydraulic Actuator — A schematic drawing of an electrohydraulic actuator is also shown, Fig. 6. The moving coil is fastened to a jet pipe which swings freely in two bearings. One is a ball bearing, the other an oil-suspended sleeve bearing which eliminates practically all friction.

Oil, pumped through the sleeve bearing into the jet pipe, discharges through a small opening in the tip of the pipe. The jet of oil from the pipe hits two receiving orifices located side by side. With the slightest deflection of the jet pipe, one orifice will receive more oil than the other displacing the piston accordingly.

If signal current increases, the coil moves into the magnetic field and rotates the jet pipe in a counter-clockwise direction. This directs flow of fluid so that the piston moves downward together with the plug of the control valve to which it is linked.

The feedback lever is connected to the piston stem by a roller and spring which permits it to follow the motion of the stem. This stretches the feedback spring as the piston moves toward a new position.

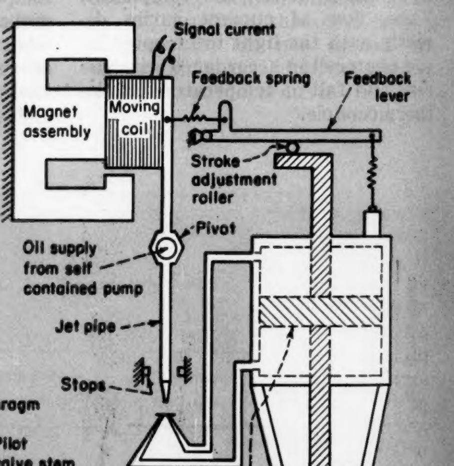
As the feedback force increases and approaches the opposing force of the moving coil, the jet pipe returns to its neutral position. Once it reaches this position, the piston stops. Its position is proportional to magnitude of signal current.

Stable Situation—All the actuators described here perform like the pneumatic diaphragm-and-spring valve. With the electrohydraulic actuator, there are some advantages such as higher thrust, greater speed and better dynamic performance. But on all these developments, there was need to keep cost down and there was no impelling urge to greatly surpass present-day performance standards.

This may indicate a situation where there is no demand for basic or drastic improvements. This applies to the controller as such since the final control element is generally the limiting element in a control system, except for the process itself.

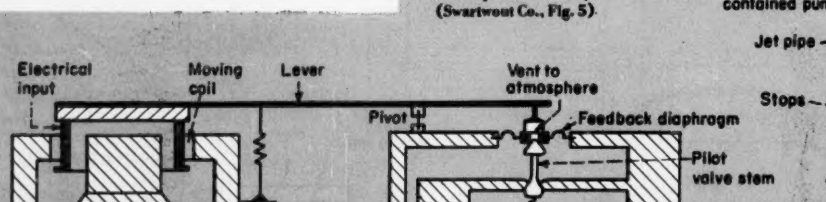
Final control elements with higher performance characteristics are available or can be made available readily, at a price.

As processes are developed that call for performances unattainable today, controllers will enter a new cycle of major perfection. Until then, we may face an era of consolidation rather than one of revolutionary novelties.



Electrohydraulic actuator deflects jet to move valve. (Askania Regulator. Fig. 6)

Electropneumatic relay (Swartwout Co., Fig. 5)



Where Primary Elements Are Headed

Theodore R. Olive
Senior Associate Editor

Primary measuring devices are the heart of process control—without them, no control. Most are good, but better ones will be needed. In some cases no satisfactory elements now exist.

What is the status of primary elements for process control today? This question, put to a number of engineers prominently associated with the use of process instrumentation, brought forth some general areas of agreement. Much of it is adequate for present needs and instrument companies seem aware of the directions for future development. However, there are areas in which satisfactory primary elements are now lacking, and pretty general improvement will be demanded of instruments if process control is to advance into the era of optimization discussed by Slater (p. 251).

An instrument primary element, or transducer, is a device which is able to detect a process variable. Process variables may be classified roughly into those which apply to properties of the process environment—the so-called environmental variables—and those depending on properties of the process material itself. The present article deals with some of the first group—temperature, pressure, level and flow. The second group, comprising mainly composition variables and their associated analytical measurements, has become so important with the advent of extensive in-stream end-point analysis that it has been made a separate and much longer article (see Aikman, p. 266).

In general, it is possible today to gain any desired precision in measuring the environmental variables—provided one is willing to pay for high precision. Average instruments, with average installation and care, are usually good to 2 to 4% accuracy, or better. It is a common complaint, however, that some types lack reliability, require too much maintenance and cost too much. There is a constant demand for instruments which will more uniquely measure the property desired. For instance, many instruments for variables other than temperature are nevertheless temperature-sensitive, and some are sensitive to line voltage variations. There is a demand for instruments depending on direct measurements, rather than inferential.

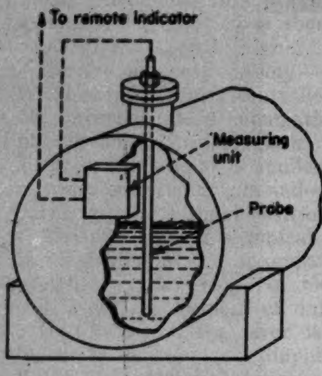
Then, there are the gaps in present satisfactory instrumentation. Among these are instruments for high-temperature measurements on flowing gases, for high-temperature pH, and for several kinds of flow metering including high-pressure pulsating flow, slurry flow, and very low fluid-flow rates.

Temperature

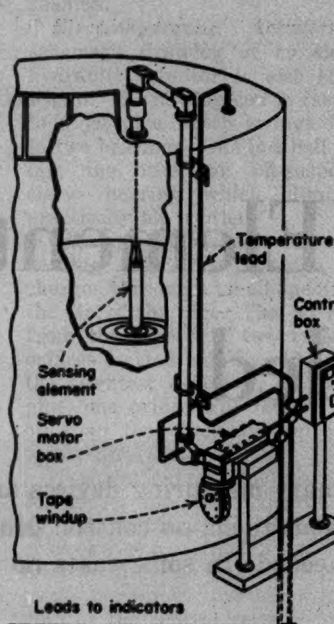
Temperature is an area where the need for faster response is often heard. Protecting a thermocouple to avoid contamination means added measuring lag. So the demand is for better metallurgy to assure uniformity and non-contamination, preferably without protection. Improvements in temperature measurement are gradual, with fundamentally new ideas introduced rather infrequently. Thermistors, which had just been brought out at the time of our 1952 review, have still not made a great deal of progress as primary elements despite their occasional use in instruments as temperature compensators. One new idea which stems from the bonded-wire strain gage is a wafer-like resistance thermometer which is cemented to the surface whose temperature is to be measured, thus assuring intimate contact and rapid response.

Pressure

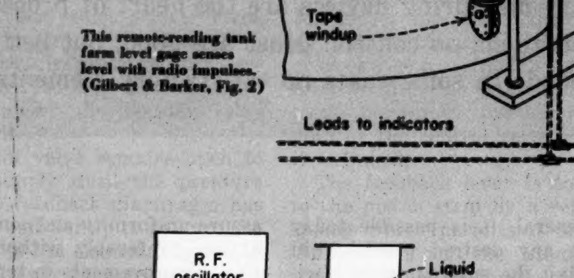
Much of the demand for better environmental transducers comes from the military and rocket field, rather than from processes. Demands for extreme precision and for freedom from rapid-pulsation errors are largely in this class. One answer to the precision problem is the Electromanometer developed by Consolidated Electrodynamics. Here the movement of the measuring bellows is automatically opposed by a force just sufficient to null its movement. Any movement of the bellows due to a pressure change displaces a differential transformer and produces a voltage signal which is amplified to drive



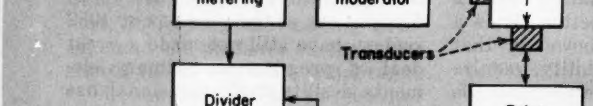
Capacitance measurement of liquid and solid levels is taking on new importance. (Fielden, Fig. 1)



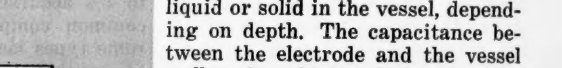
This remote-reading tank farm level gage senses level with radio impulses. (Gilbert & Barker, Fig. 2)



Level can be sensed by timing acoustic waves reflected from liquid surface. Second wave path is for reference. (Gulton, Fig. 3)



Mass meters which measure angular momentum need no density correction. (G.E., Fig. 4)



Velocity-type mass meter measures density, then computes mass flow. (Potter, Fig. 5)

a servo motor. The motor positions a digital pressure read-out as well as a feedback potentiometer, the latter controlling the current through an electromagnetic pressure balance to restore the bellows to the original null position.

Aside from exceptional cases, pressure transducers available commercially are quite suitable for ranges from high vacuum to 20,000 psi., or higher. Principle problems involve corrosion in some cases, over-ranging, rapid pulsations, and temperature errors. The pulsation problem is being handily solved in many instances by strain-gage transducers.

Liquid and Solids Level

Very considerable development has taken place in liquid and, to some extent, in solids level measurement in recent years.

Perhaps the most generally useful of the new electronic methods is capacitance level measurement. The simpler and older method of using capacitance is to employ high- and low-level probes which simply have to detect the presence of an air-liquid or air-solids interface. The newer method now being introduced by several manufacturers (Fig. 1) involves the use of a continuous insulated electrode which is more or less submerged in the liquid or solid in the vessel, depending on depth. The capacitance between the electrode and the vessel wall varies with the dielectric character of the material between them. If air fills the entire space, one value obtains. If the space is filled

with liquid or solid, a different value of system capacitance will hold. With intermediate values of level, the measuring unit will determine intermediate values of capacitance and its indicator can be calibrated in terms of level.

"Radio broadcasting" as a means of level detection has been put to use in one instrument (Fig. 2) for tank farm gaging. Instead of a float, on the end of a perforated tape there is a small cylindrical sensing element containing a wire antenna which penetrates the liquid level $\frac{1}{16}$ in. It is supplied with minute r.f. signals from a one-tube transmitter. Return signals travel back up the cable, their strength depending on the submergence of the antenna. Deeper submergence weakens the signal. An amplifier-receiver operates to hold a constant signal corresponding to $\frac{1}{16}$ in. submergence through control of a servo motor driving the tape wind-up. Drum position is then telemetered by a null-balance system over distances up to five miles. There liquid depth can be read to feet, inches and $\frac{1}{16}$th's.

Ultrasonic level gaging is another of the newer methods. One method, shown in Fig. 3, employs two transducers secured outside the tank wall. Pulses of ultrasonic energy are transmitted to the liquid surface by one transducer, and over a fixed distance to the opposite wall by the other. Reflected pulses re-trigger the pulse transmitters. Time for the round trips is measured electronically and interpreted as liquid depth. The fixed-distance transducer provides a continuous correction standard so that an accuracy of 1% is said to be possible.

Other developments in this area include an increasing interest in digital level transmission to tie in with the new developments in data handling; and further use of gamma-ray detection for both solid and liquid levels. This is particularly true where access to the level would be difficult by other methods.

Fluid Flow

In an ever-larger number of cases a demand for higher flow metering accuracy is making itself heard. This will be still more urgent as the integrated data-handling systems begin to make themselves felt. Military demand has already resulted in a number of important developments in flow metering in the last few years. Some of these are likely to become of increasing importance to process industries.

In addition to the well-known positive-displacement meters, which are inherently accounting machines since their primary response is integrated flow volume, we have the flow-rate-responsive instruments whose primary response is rate of flow. These require an added integrating function if total flow is needed for accounting. With either type, of course, density correction may be needed for greatest accuracy. This is one of the main reasons for the very active development of mass flow meters since our 1952 review.

The new mass flow meters are of two basic types, true mass meters which respond to rate of mass flow, and volume-flow-rate meters with automatic density correction. Several true mass meters are now on the market, all similar in general principle although differing considerably in the means of applying the principle. Such meters impart angular momentum to the fluid as it flows through the pipe, then measure the torque required to remove this momentum.

Fig. 4 is typical of several meters employing this principle. The fluid passes through a radial impeller driven at constant speed, there picking up angular momentum (swirl). It passes a central disk to eliminate mechanical coupling effects and then loses its angular momentum by passing through a second radial impeller which is free to move but is restrained by a spring. Its torque, as measured by the spring, is proportional to the mass flow.

Other meters working on a similar principle include the gyroscopic type and the Li coriolis-force meter, both commercialized by Norwood. In each of these, mass readings are produced directly, without need for density or viscosity corrections.

Rate-of-flow meters generally are of the fixed-orifice, variable-head type (orifices, venturis), the variable-orifice, fixed-head type (rotameters), or the stream-velocity type (turbine, ultrasonic and electromagnetic meters). Several of these are now available with automatic density correction to read out mass flow rate. One of them is illustrated in Fig. 5. This is a turbine-type meter which, through the action of the rotating magnetic field of the rotor, produces an alternating current in the pick-up coil having a frequency proportional to the flow velocity. Electronic measurement from a displacement-type density transducer is multiplied by a voltage proportional to the frequency to yield a mass flow indication.

Another interesting new velocity meter is the ultrasonic type, developed by Maxson and, available industrially through Fischer & Porter. The meter is a tube containing two diagonal acoustic paths having a crystal transducer at either end. One path points upstream, the other down. In each path pulses of ultrasonic energy are projected by a transmitter at one end to a receiver at the other. By a re-triggering arrangement controlled by the receiving crystals the transit time for the pulses is calculated. Their difference is proportional to the flow velocity but is independent of acoustic velocity in the fluid.

A fifth crystal transducer is used to determine the density of the flowing fluid. The voltage across it is proportional to the product of fluid density and acoustic velocity so that dividing it by a voltage proportional to acoustic velocity (obtained from the circuit of one of the two acoustic paths), and combining the result with the velocity measurement in a computer, a mass velocity indication results. The computer also totalizes flow.

Needs For Future

Some of the aims which instrument men see for the future of primary elements can be summed up as "more signal from less hardware." They are looking for less costly, more reliable instrumentation that will be less complex and easier to maintain, more specific, faster in response, less affected by extraneous influences, and able to operate under more extreme conditions of temperature, pressure and —particularly for nuclear plants— radiation. Then there is a whole new area that is certain to become important as digital data handling becomes general, that is, primary elements with direct digital readout to avoid the need for digital converters.

Manufacturers are familiar with these needs. They and user instrument engineers are devoting much research to their solution. With the extra reliability that transistors, magnetic amplifiers, printed circuits and hermetically sealed components will bring to industrial instrumentation, the goals seem likely to be attained.

Process Control by Analytical I

Control specialists look to analysis instrumentation to provide much production facilities in the chemical process industries. Herein are during the recent past. Analysis instruments still in the laboratory

Since the last Instrumentation report appeared in *Chemical Engineering* five years ago, the industrial importance of rapid, reliable, accurate analysis has increased considerably. Techniques in use at that time have been consolidated; methods which were just emerging from the laboratory now are accepted in the plant. Other techniques, which until recently were unheard of outside academic research laboratories, are now about to come into process use.

It is probably fair to state that instrumentation for the automatic control of environmental conditions, and the understanding of this instrumentation and its application, have reached a reasonable level of maturity during the last five years. In the five years ahead, analysis instrumentation can be expected to carry an ever-increasing share of the burden of making process plant more easily operable and more efficient, and to reach a corresponding state of maturity and industry acceptance.

Extensive knowledge of automatic control has become so widespread that lack of basic theoretical tools, which can be made rather simple, is no longer a barrier to successful system design.

Rather, today's limitations are lack of knowledge of process statics and dynamics. Development of on-stream analytical instruments is helping to emphasize this shortcoming.

Appreciation of the value of timely data is growing, with all that this implies for process and instrument dynamics.

In this review, we shall emphasize the instruments themselves and their applications, since the space allotted makes it impossible to include sampling systems and automatic control considerations.

The instruments are grouped as Spectroscopic and Non-Spectroscopic. The former tend to be much more selective or responsive to a given component of a mixture in the presence of any variation in the other components. They also tend to be much more complex and expensive although there are many exceptions.

Although this review is oriented toward process and application, it would not be complete without a glimpse at some of the newer techniques. At their present stage of development these techniques are found in the research laboratory. But by extrapolation of trends, the author expects them to evolve into plant instruments soon.

NON-SPECTROSCOPIC

Methods included in this category generally are simpler and more reliable than spectroscopic methods. However, in some cases they are much less selective, or not selective at all.

The fact that the process industries use so many for monitoring or control is attributable not only to their comparative simplicity, but also to the fact that many process streams are binary or pseudo-binary in composition. We shall stress new methods or ones with the greatest application potential. Not discussed here are methods such as pH and redox, electrical conductivity, and automatic titrators.

Thermal Catalytic Converter

The principle of this instrument is not new, but recent developments have increased selectivity considerably. Hydrocarbon or other combustible vapor to be analyzed is mixed with excess air and led over a catalyst contained in a cell. Heat of combustion is measured by a differential thermopile and recorded.

Recent advances in catalyst manufacture permit selection of a catalyst on which will burn only one specific gas. At the present time, catalysts can be specified on which will burn any hydrocarbon up to and including all the C_4 compounds. As many as three catalytic cells, each with a different catalyst, may be placed in series to obtain a multi-component analysis.

The time constant is about a minute and the price will be "competitive" with gas chromatographs. Ranges between 0-1% and 0-100% may be obtained with accuracy approaching 1% of full scale. This instrument will be available commercially later this year.

Flow Colorimeters

In their simplest form, these devices consist of a light source, filter, sample cell and detector. Filters are used to obtain comparatively narrow band widths to enhance selectivity.

Ratio-recording flow colorimeters also are available. A single beam of light is passed through the sample and split into two beams. One beam passes through a filter direct to a photocell. The other passes through a reference (non-absorbing) filter to a second cell. The ratio of outputs from the two photocells is recorded. In this way, the effect of variations in turbidity, window deposits, etc. are substantially eliminated.

Applications for these instruments include monitoring of filtration processes (by turbidity measurement), wax-decolorizing processes and chlorine dioxide solutions.

Thermal Conductivity

A new twist in thermal con-

Instrumentation

of the future progress toward completely automated reported the significant developments in this field stage are evaluated for possible future plant use.

A. R. Aikman

Schlumberger Well Surveying Corporation

ductivity analysis of gases was introduced about a year ago. Conventional thermal conductivity analyzers rely on the fact that the rate of heat loss from a heated filament in a small chamber is proportional to the thermal conductivity of the gas in the chamber.

In this new design, Fig. 1, the thermal convection of the gas is used as well. One cell is made several times larger in diameter than the other. The difference between rate of heat loss in a large cell and in a small cell becomes greater as the conductivity decreases, and as the molecular weight of the gas increases. As a result, the output of the instrument can be weighted in favor of one component.

This instrument has found application in monitoring some hydrocarbon and fuel-gas streams.

Moisture in Gases

A new approach to moisture-in-gas analysis, developed originally by Du Pont, is now embodied in a commercial instrument available from several manufacturers. This exceptionally simple instrument continuously and simultaneously absorbs and electrolyzes any water present in the gas stream.

The absorbing material is a thin, viscous film of phosphorus pentoxide in contact with two specially wound platinum wires inside an insulating tube. A d.c. voltage applied to the wires continuously electrolyzes the water as it is absorbed. The current drawn is proportional to the humidity of the gas, if constant flow rate is maintained.

Response is linear down to 1 ppm. The instrument is inexpensive, as would be expected from its simplicity. Typical applications are for moisture in natural gas, Freon, bottled gases, compressed air, and research studies.

Sonic Methods

Details of two plant instruments for gas analysis were released over two years ago in Britain[1,2] and one U. S. manufacturer makes one. The basic physics of these instruments is identical. Velocity of sound in a gas composed of a single type of molecule is:

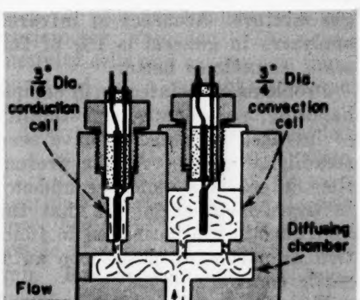
$$V = (\gamma RT/M)^{\frac{1}{2}}$$

where V is sound velocity, γ is the ratio of specific heats of the gas, R is the gas constant, T the absolute temperature and M the molecular weight.

The sound velocity is independent of pressure. In gas mixtures, the effect is additive and can be calculated in advance from a knowledge of the molecular weights and specific heats of the components.

Obviously, the method is not selective. But it is particularly suitable for determining an impurity of high molecular weight in a gas of low molecular weight, or vice versa.

In one instrument, the gas to be analyzed is contained in a tube between a transducer fed by an oscillator, and a microphone. The time interval between emission and reception of a sound wave is inversely proportional to velocity and is measured easily and accurately as a phase difference by an electronic meter.



New gas analyzer uses thermal convection and conductivity. (Mine Safety Appliances, Fig. 1)

For example, in a 30-cm. tube, the phase angle introduced by mixing 1% of CO_2 with air is 2.96° at 3,000 cps. For 1% bromine vapor under the same conditions, it is 21.6°. The phase angle measured is nearly proportional to concentration. Temperature control or compensation is necessary for accurate measurement.

The other instrument has been used to measure the concentration of C_7F_{14} vapor in air. In it, the velocity of sound at a controlled temperature is determined by measuring the resonance frequency of a tube containing the mixture. A servomechanism maintains a state of resonance when composition is changed.

The transducer-detector elements of these instruments can be built into process pipes. These instruments may find application where rapid response is needed, or where the corrosive or radioactive nature of the gas make it undesirable to remove gas from the process pipe for sampling.

Ionizing Radiation

Ever since the Geiger-Mueller counters and ionization chambers were first developed, people have studied how the composition of the filling gas affects the characteristics of these devices. Within the past few years, the problem has been re-studied from the analysis point of view.

Among the factors affecting the current in an ionization chamber are the type of ionizing radiation,

the ionization cross-sections of the gases in the chamber and the potential difference.

On several grounds, a beta-ray source such as Sr-90 is the most effective and convenient source of ionizing radiation. Voltages around 100 are commonly used. The effects of gas composition on ionization current are roughly additive in proportion to mole percent and ionization cross-section of each component, although there are many anomalies due to ion recombination effects.

Applications[3] include analysis of argon (1-13%) in ammonia synthesis gases and ammonia. In the case of the synthesis gas, ammonia and hydrogen are removed before determination of the argon content.

An instrument operating on a similar principle has been used as a detector in vapor chromatography equipment.[4] A similar instrument, employing an alpha-particle source, was used to study diffusion processes because of its very high speed of response.[5]

Although these techniques are non-selective, they find use as accurate and speedy methods to supplement or replace other non-selective gas analysis instruments.

Refractive Index

Today, at least three manufacturers are offering rugged explosion-proof on-stream refractometers with precision between one part in the fourth decimal place and one part in the fifth decimal place. Temperature compensation, an essential for reaching such precision, is built into the instruments.

Despite the necessity for having a clear and clean sample stream and the fact that the technique is non-specific, a substantial number of these instruments are working on continuous monitoring or control applications. Examples are the fractionation of cyclohexane and n-hexane with refractive indices of 1.42623 and 1.37486 respectively. This difference is sufficient to enable composition to be determined within 0.1%.[6]

Refractometers also have been used on direct automatic control of operations such as the blending of butadiene and styrene, and on continuous control of methyl-cyclopentane-cyclohexane fractionation.[7] Process refractometers are comparatively simple and rugged. For this reason, they may be preferred over alternative instruments such as infrared when working with binary streams.

SPECTROSCOPIC METHODS

Infrared

In the period covered by this survey, no fundamentally new principles of infrared instrumentation have been introduced. There are still two principal types available for plant applications: dispersive and non-dispersive.

The non-dispersive type can be subdivided further into two groups: the negative filtering with non-selective detector and the positive-filtering (Luft) type. Of the more than 1,000 process-control instruments which have been sold, the great majority are the non-dispersive, positive-filtering type.

A fundamental reason why infrared analyzers are used so widely, especially in the petroleum and petrochemical industries, is that many of the groups in organic molecules display characteristic absorption bands in the infrared region. These spectra have their origin in the natural frequency of vibration of the groups. Examples are the CH_3 absorption band at 3.3μ and C=O band at $5.3\text{-}6.4\mu$ wavelength.

Sensitivity of infrared instruments may be adjusted from high percentages of a key constituent down to parts per million in favorable cases, such as CO in air. Selectivity can be extremely high when components of the mixture do not have overlapping spectra. But sensitizing the instrument to respond to only one constituent of a complex mixture with spectra that overlap partially can be troublesome. Each application must be evaluated independently.

One advantage claimed for the dispersive-type infrared instrument[8] is the comparative ease of adjustment when the spectrum is known for each constituent of the gas mixture. Accuracy of infrared analyzers in general is 1% of full scale, sometimes better.

Problems associated with sample handling, maintenance and stability of infrared instruments have been steadily overcome. At the present time, there is sufficient confidence in some installations so that the instruments are permitted to function as part of a closed-loop automatic control system.[9, 10, 11, 12]

Nearly all process infrared analyzers are used on gas streams. On liquid streams, sample-handling problems are apt to be more difficult and very thin absorption cells must be used. If there is appreciable viscosity, it may be difficult to force the sample through the cell at an adequate rate. Nonetheless, liquids such as water (0-0.4%) in liquid SO_2[13] have been analyzed.

The great majority of these instruments at present carry out their control function through the human operator. Infrared instruments continue to be one of the most powerful means of in-process analysis, and their use is certain to be extended.

Mass Spectrometry

During the last five years, mass spectrometry has changed considerably and has evolved from the laboratory to a variety of applications in process control.

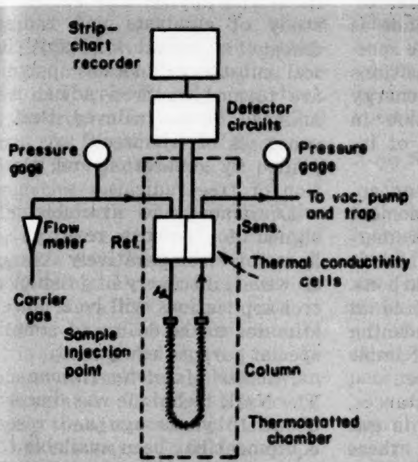
Relatively speaking, mass spectrometers are fast, very sensitive, versatile and have very high selectivity and accuracy.[15] If you take into account the associated vacuum system, they are rather complex. However, within the past few years, electronic equipment has steadily gained wider acceptance in process plants. Simultaneously, mass spectrometers have been simplified to the point where the latest model has but 9 tubes and weighs little over 100 lb.

The mass spectrometer makes possible the fairly rapid, semi-continuous analysis of multicomponent mixtures when appropriate data-reduction and computation facilities are available. For example, a 20-component mixture can be analyzed completely and the composition printed out within a 10-min. cycle.[14]

Monitoring of one or a few mass peaks also is practicable and correspondingly faster. Typical of such applications are monitoring of sulfur in sulfur-recovery tail gases[17] and of acetylene produced by the Wulff process.[8]

Individual samples may be as small as 0.1 ml. of gas or 0.001 ml. of liquid. The instrument is so versatile that it can handle a range and concentration of sample material that varies from 5-10 ppm. O_2 or N_2 in argon, to major percentages of hydrocarbons in LPG. Accuracy will approach a few tenths of 1%.

In the very near future, we can expect further improvements in the instrument and associated sampling systems. At the same time, the processes themselves will be understood better. These developments will lead to a few direct automatic-control applications where a relatively small amount of computa-



Schematic diagram of vapor chromatograph analyzer. (Fig. 2)

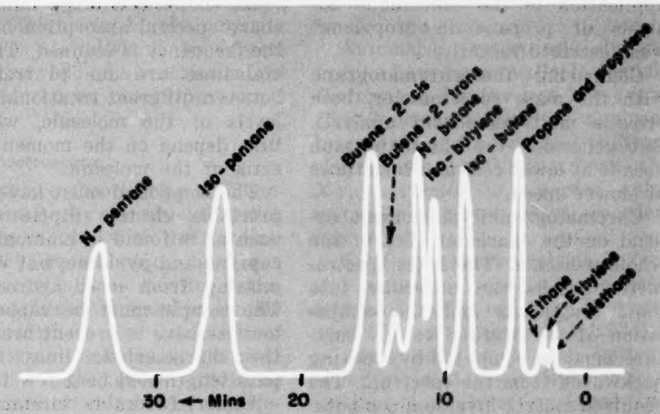


Chart record from vapor chromatograph, low-boiling hydrocarbons C_1-C_5. (Fig. 3)

tion is required on the spectrum.

Because it delivers a great deal of information relatively fast, one mass spectrometer in conjunction with special-purpose computing and data-handling equipment conceivably could analyze automatically and perhaps control several multicomponent plant streams.

Vapor Chromatography

Vapor chromatography recently has been hailed as "the greatest advance in analysis of volatile petroleum constituents since the adoption of spectroscopic methods." But, the technique is by no means new in conception.[18, 19] Validity of such a claim is based on ability to separate microgram samples into their components with no overlap of fractions. And it is done at comparatively low cost, using little or no electronics.

Symptomatic of the very recent mushrooming of interest in this country is the increase from two or three manufacturers of laboratory and plant instruments in early 1955 to 9 or 10 at the present time.

In the elution-partition method now most favored, Fig. 2, a continuous stream of carrier gas flows from an external bottle at a constant rate ranging from 5 to 400 ml./min. Although helium generally is preferred, hydrogen and nitrogen also are used.

First, the carrier gas flows through the reference side of a thermal conductivity cell, then past a sample injection point to the partition column. Liquid samples, 0.01-1.0 ml., or gas samples, 0.25-25 ml., are injected by syringe or by a variety of valve devices. The sample vaporizes into the carrier gas which sweeps it into the column.

The partition column itself usually is ¼-in. dia. and a few feet long. Inert packing, such as Celite, supports a high-boiling organic liquid such as dinonyl phthalate in which the vapor components are slightly soluble.

Since all the components vary in partition coefficient between carrier gas and the stationary column liquid, they are washed through and out of the column (eluted) at differing rates. If the column is long enough, each component will be borne by the carrier gas from the far end of the column at a different time.

The stream is led to the measuring side of the conductivity cell, so that any change of vapor composition causes an unbalance in the detector circuits. Output signals from the cell are applied to a potentiometer recorder. The conductivity cells and column are thermostatted to a suitably elevated temperature, up to about 300 C.

Analytical results are recorded as a series of peaks on a strip chart, Fig. 3. Components are identified by measuring the elapsed time between injection of the sample and elution from the column. The amount of each component is proportional either to the peak height or to the area under the peak. Thus the instrument records a molecular spectrum by a process analogous to scanning.

In some instruments, an automatic integrator determines the area under each peak. Total time for analysis varies between a few minutes and an hour, depending upon the ease with which the components can be separated and the range of molecular weights.

Dispersion and hence selectivity of the instrument can be made extremely high by choice of the appropriate liquid phase and operating parameters such as gas flow rate, temperature, nature of carrier gas and column dimensions. As an example, it is possible to separate and identify C_4 fractions including n- and isobutane, isobutylene, trans- and cis-butene-2, butene-1 and butadiene on a routine laboratory or even an onstream basis.

Sensitivity of chromatographic equipment is such that traces as low as 50 ppm. of air in Freon can be detected in three min., although reproducibility may suffer at such low levels. For the determination of important trace components, the sample must be sufficiently large to give a reliable response for the trace material. Consequently, the major constituents may drive the recorder pen off scale.

Instruments recently available for plant use employ a series of attenuators connected to the detector circuit in timed sequence. Thus, as the column elutes, each peak is attenuated by a pre-selected factor sufficient to keep the pen on scale. The sensitivity is practically unlimited in trace analysis if the component peaks are far apart.

Explosion-proof instruments are being manufactured now by at least two companies for use onstream in hazardous locations. An

application to the continuous analysis of propane in propylene[20] was described recently.

Comparing the chromatograph with the mass spectrometer, both provide multi-component analysis. But generally, the chromatograph does it at lower cost and sometimes at slower speed.

Chromatographic phenomena depend on the characteristics of the whole molecule. The mass spectrometer breaks the molecules into ionic fragments and the composition of the original sample mixture must be computed by working backwards from the spectrum. The required matrix inversion computation necessitates the use of a digital computer if reasonable speed and high accuracy are expected.

Comparing the chromatograph with infrared analyzers, the infrared is substantially faster for a single component, but more complex. Reliability and serviceability of the infrared units have been improved greatly in recent years.

The chromatograph is more versatile. Its cost may vary from about $1,500 for a laboratory instrument to over $10,000 for an automatic, explosion-proof, on-stream instrument with reproducibility of within 1%.[20]

No chromatograph has yet been used in closed-loop automatic control, but the potential here is considerable.[21]

Radio-Frequency Spectroscopy

Three closely related analytical techniques—nuclear magnetic resonance (NMR), microwave absorption, and electron paramagnetic resonance (EPR)—show potential for process analysis. The most advanced of these in an instrumental sense is NMR which is just graduating from research laboratory to process control laboratory use.

These are truly spectroscopic techniques whose close resemblance is due to use of electromagnetic radiation phenomena which take place at radio frequencies (generally megacycles and up).

The important developments have all occurred in the last decade. Although evaluation of these techniques for application in the process industries is far from complete, already it is clear that some, if not all of them, have possibilities as far-reaching perhaps as infrared analysis or mass spectrometry.

Microwave Spectroscopy—At frequencies of tens of thousands of megacycles, each observable compound exhibits a large number of sharp spectral absorption bands as the frequency is scanned. The spectral lines are due to transitions between different rotational energy levels of the molecule, which in turn depend on the moment of inertia of the molecule.

The compound must have an appreciable electric dipole moment such as is found in ammonia, mercaptans and pyridine, but which is missing from most hydrocarbons. The sample must be vaporized at low pressure to prevent broadening the characteristic lines. Sample path length will be a few feet.

Under favorable circumstances, such as prevail with ammonia gas which absorbs strongly at these frequencies, the minimum detectability is about one part per million. As molecular weight increases, it becomes more difficult to detect the molecule. For example, butyl mercaptan is difficult to detect.[22]

Microwave techniques have been very successful at the research level for determining electric dipole moments accurately and for characterizing the structure of some molecules.

At the present time, there are no obvious industrial applications, but some may be uncovered by continued research. Equipment is not commercially available.

Electron Paramagnetic Resonance—In order for a material to react to this form of spectroscopy, it must contain unpaired electrons in the atomic electronic shells to give the atom strong paramagnetism. Then, if a solid, liquid or gaseous sample is exposed to microwave energy and simultaneously to a fairly strong magnetic field (a few thousand gauss), it will absorb energy.

Much work with EPR has been done at a research level, mainly on solid-state physics studies in the communications industry but little in the process industries. However, instrumentation for industrial research use has just been marketed by two companies. This will give considerable impetus to industrial utilization of the techniques.[27]

Classes of samples which are detectable by EPR include: vapors of alkali metals such as Li, Na, and K; rare earths; iron group metals, palladium, platinum and uranium groups; molecular oxygen, NO and NO_2; and free radicals.

Study of free radicals, which are detectable in concentrations as low as parts per billion in some cases, will open up some very important industrial applications such as the study of catalysts and radiation damage in polymers. Many chemical substances, notably polymers, are formed by free-radical mechanisms. It is believed that the processes of life itself are accompanied by generation and destruction of free radicals.

Equipment now available is designed for varied research use, hence is comparatively complex. However, discovery of product control applications will be a powerful stimulus to the design of simplified special-purpose equipment.

Nuclear Magnetic Resonance—The NMR technique was discovered about 10 years ago and research equipment has been available to industry for the last 4-5 years. This technique has grown more rapidly than other types of radio-frequency spectroscopy, to the extent that simplified equipment suitable for control-laboratory use has just become available commercially.[23]

NMR measurements are based on the fact that radio-frequency energy is absorbed by about 100 isotopes of the chemical elements when they are placed in a magnetic field. Only those elements can be detected whose nuclei have a magnetic moment and an angular moment. This includes H, F, Li and P, for example, but excludes the common isotopes of C, O_2 and S.

In industrial control laboratories, NMR has already been applied with some success to product identification of petroleum and chemical materials and to moisture determination in solid food products. The technique is based on the nondestructive examination of the properties of the atomic nucleus itself, hence the name. It is not nucleonic, which implies the use of high-energy particles to disrupt or disturb the nucleus.

In its usual form, the apparatus consists of an electronic detector and either an electro or permanent magnet in whose field the sample is placed.[24]

NMR absorption is exhibited by those nuclei, such as hydrogen nuclei (protons), which have a magnetic moment. Protons in any compound of hydrogen behave like small magnets spinning about an axis. When the compound is placed in a magnetic field, the protons precess at a very definite frequency.

A good mechanical analogy is a simple gyroscope, which precesses at a definite speed in the earth's gravitational field. There is a simple relationship between the fre-

quency of precession F and the magnetic field strength H_o, where $F = H_o(2\mu/h)$. Here μ is the magnetic moment of the spinning nucleus and h is Planck's constant. For hydrogen in a field of 1,700 gauss, the frequency is 7.25 megacycles; for phosphorus, it is 2.9 megacycles/sec.

The magnetic effect of the spinning nuclei is extremely small and resonance must be used to detect it. One feasible circuit is shown in Fig. 4. Here the sample tube is placed in the field of the magnet and is surrounded by a coil to which a current is applied by an RF generator. The coil is part of a highly tuned resonant circuit.

When the magnetic field is slowly swept through the nuclear-resonance value, by adjusting the current passing through the magnet coils, energy absorption occurs. If energy absorption is recorded against magnetic field strength, the NMR spectrum is obtained. Area under the line is proportional to the quantity of the particular nucleus present. Overlapping of lines is no problem in NMR as the spectra of different nuclear species are very well separated.

This branch of spectroscopy normally is subdivided into "high" and "low" resolution techniques for convenience as well as for basic reasons. A low resolution apparatus uses a magnet with a field homogeneity over the sample volume of one part in 10^5 or 10^6; high resolution requires homogeneity of one part in 10^6 to 10^8.

NMR, along with X-ray and nuclear techniques, is one of the few basic methods applicable to analysis of solids.

Low-resolution technique is well adapted to quantitative measurement. Currently, the outstanding application is to measure accurately the moisture content of solids, even when the solids contain hydrogen.

Further development of low-resolution instrumentation and associated sampling systems will make feasible the accurate control of moisture content, independent of particle size distribution and variable electric conductivity. Sample size may be up to 40 ml. in one apparatus.

In order to observe high-resolution spectra, the necessary field homogeneity is obtained by using specially designed magnets and small (0.1 ml.) liquid samples. The ability to identify groups in complex molecules, Fig. 5, has made NMR a very useful tool for the analytical and structural chemist. The technique is highly selective and it is not difficult to foresee where the yield of a reaction might be monitored by observing sample spectra.

X-ray Spectroscopy

X-rays are absorbed by all chemical elements by an amount which increases roughly with their atomic number. The technique has been used successfully to monitor tetraethyl lead in gasoline and in similar situations where the total lack of selectivity of the technique is compensated by the great difference between atomic number of the element being determined and all others likely to be present.

X-ray absorption analysis is reasonably sensitive and very rapid. It is most sensitive for heavy element analysis spectroscopy.

X-ray fluorescence, by comparison, is highly selective spectroscopy. An intense beam of X-ray is directed at the material to be analyzed. Each atomic species in the sample fluoresces with induced secondary radiation whose wave lengths are characteristic of the atom and whose intensity is directly proportional to the amount present.

X-ray spectra are simple, being composed of only a few sharp lines for each element—hence, the high selectivity of the technique, which today is applicable to elements from atomic number 19 (K) upwards.

Automatic recording spectrographs have been available for laboratory use for the last few years. The fluorescent beam is analyzed by scanning with a crystal (diffraction grating). Output from the X-ray detector is recorded automatically on a strip-chart recorder, Fig. 6.

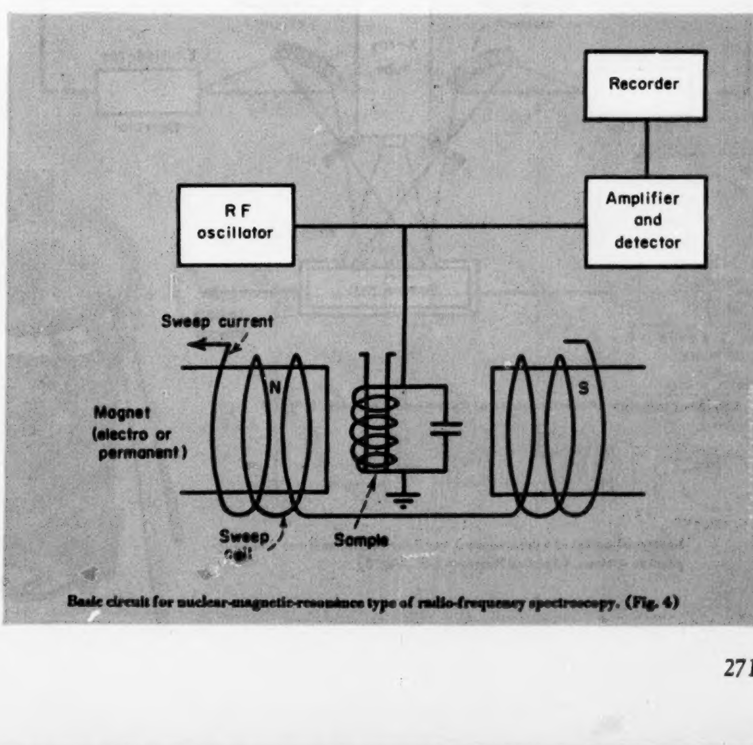
Multi-component analysis is fast and accurate. Sensitivity is such that 0.5% sulfur in oil can be measured with an accuracy of ±0.03%.[25]

Latest addition to the battery of industrial X-ray equipment is a continuous analyzer designed for process use. The technique, originally designed for control of tin coating thickness on continuous strip mills,[26] now is applicable to continuously flowing solid or liquid samples.

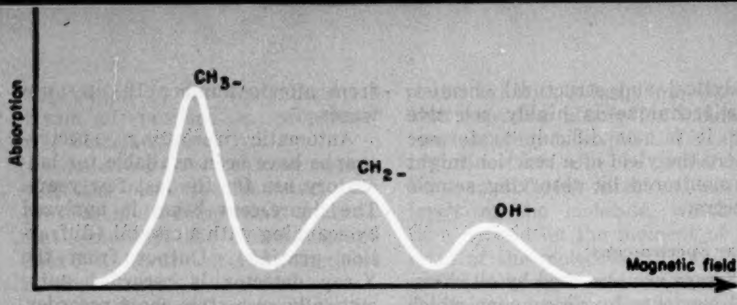
Principle is shown in Fig. 7 and equipment in Fig. 8. The recorder and control console may be located up to 300 ft. from the process unit.

Within the spectrometer head are two curved-crystal monochromator channels, each employing two Geiger counters and a rugged X-ray tube. One monochromator is adjusted to diffract only scattered radiation of a chosen wavelength into its detector. The other is adjusted to a wavelength characteristic of the element being analyzed.

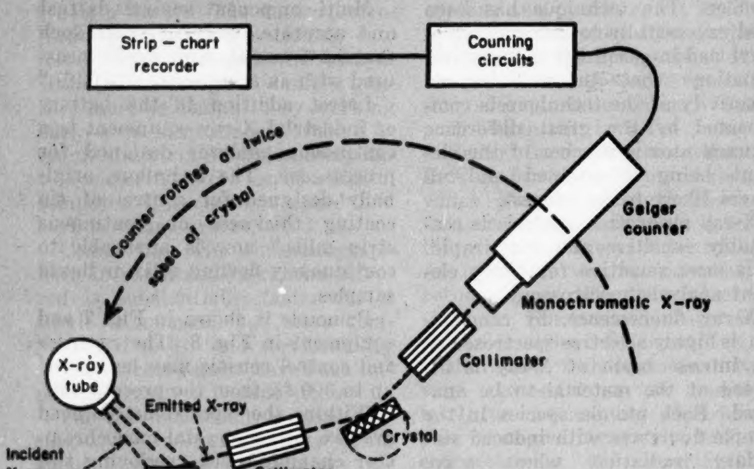
The ratio of the two detected beams, which is independent of



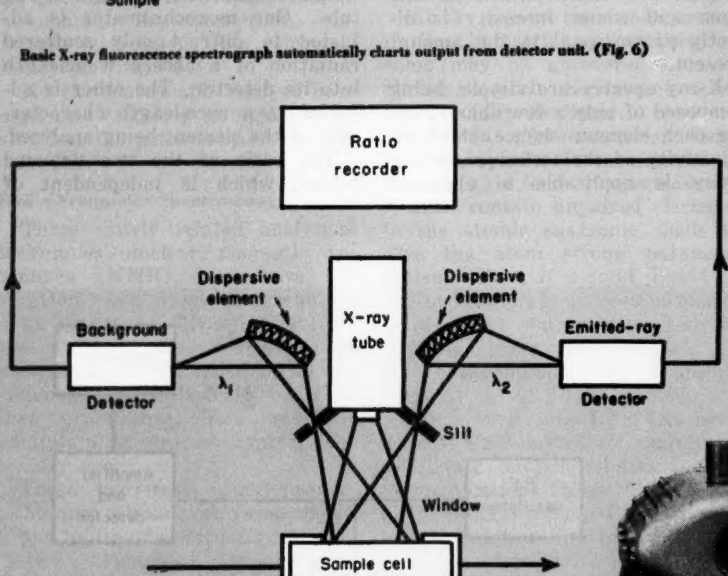
Basic circuit for nuclear-magnetic-resonance type of radio-frequency spectroscopy. (Fig. 4)



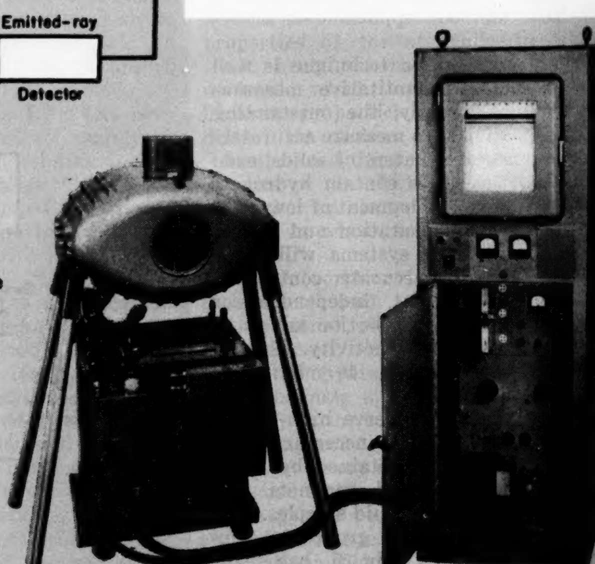
Nuclear-magnetic-resonance or proton-resonance spectrum of ethyl alcohol. (Fig. 5)



Basic X-ray fluorescence spectrograph automatically charts output from detector unit. (Fig. 6)



Operating principle of continuous X-ray fluorescence analyzer. (Fig. 7)



Industrial model of a continuous X-ray fluorescence analyzer can be applied to streams. (Applied Research Lab., Fig. 8)

source strength, is continuously recorded and is related linearly to concentration. In solutions of heavy metals such as copper and vanadium, the lower limit of accurate detection generally is about 50 ppm. of solute.

X-ray fluorescence spectroscopy in some respects is competitive with optical emission spectroscopy. It is not as sensitive for trace analysis. But the X-ray spectra are much simpler and the instrumental techniques are also simpler and probably prove easily adaptable to direct process use.

Ultraviolet Spectroscopy

In research and analytical laboratories, ultraviolet spectrometers are used quite extensively, but the numbers applied on-stream are a mere fraction of the number of infrared instruments now in use.

Saturated hydrocarbons have no useful ultraviolet spectra. But unsaturated hydrocarbons especially in the aromatic category, halogens, and mercury vapor have very specific types of spectra in the instrumentally useful wave-length range up to about 1,500 A.

Principle of a commercially available non-dispersive process instrument is shown in Fig. 10. A somewhat similar instrument developed by Du Pont uses a servo-driven cam to maintain a null-balance absorption condition and a servo to perform a periodic standardization.

The same sample passes through both sample and compensating cell

which are different lengths. Thus, instrument response is largely independent of cell-window fouling. Sensitivity of this instrument has led to use on plant vapor streams containing 0-0.1 ppm. chlorine, 0-1 ppm. mercury vapor in air, 0-300 ppm. benzene.

These instruments are absorptiometers rather than true spectrometers; but selectivity can be improved where necessary by the use of filters.

Nucleonic Techniques

Nucleonic techniques involving the bombardment of the sample with neutrons have been used for about the last 15 years in the oil-well surveying industry. A natural source of neutrons, such as Po-Be or Ra-Be is lowered down the well along with suitable gamma-ray detection equipment.

Neutrons emitted by the source become moderated by colliding repeatedly with atomic nuclei (predominantly hydrogen) in the surrounding formation. By moderation, we mean that the neutrons are slowed down from initial energy of 3-5 mev., to thermal energies.

The thermal neutrons may be captured temporarily, then ejected by a nucleus, leaving the nucleus in an excited state. The excited nuclei instantly return to the ground state with emission of a gamma-ray of energy characteristic of the nucleus. Thereby, the well surveyor can estimate the composition of the formation and its fluids.

Typical of this capture-gamma spectrum is one for cobalt, Fig. 9. Equipment for the study of these gamma-ray spectra is available for research-lab use.

The gamma-ray spectra of the elements do not fall into a regular predictable series as do the X-ray spectra. But most comprise a few strong sharp lines in the range 0.5-10 mev. Under suitable circumstances, monitoring of the spectrum could be the basis for highly selective process analysis, with the advantage that no detrimental residual radioactivity is likely to be induced in the process sample stream. A certain amount of development work has been done along these lines. Some fruitful applications to elemental analysis are certain to be discovered.

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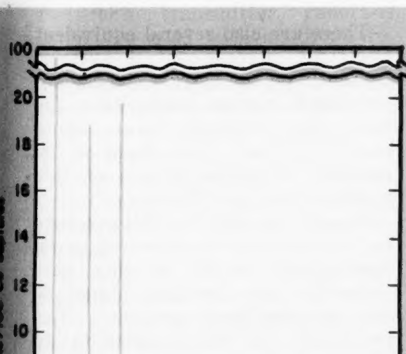
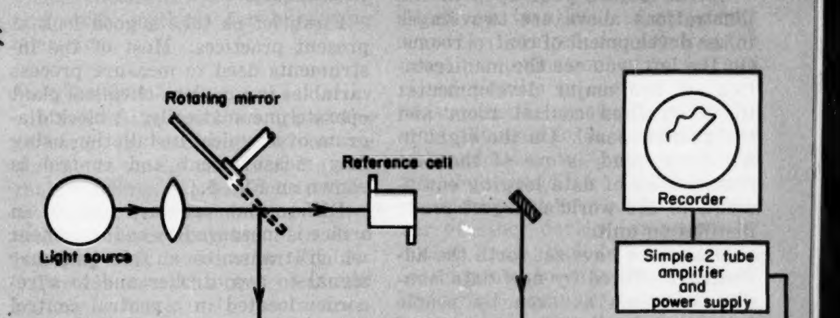
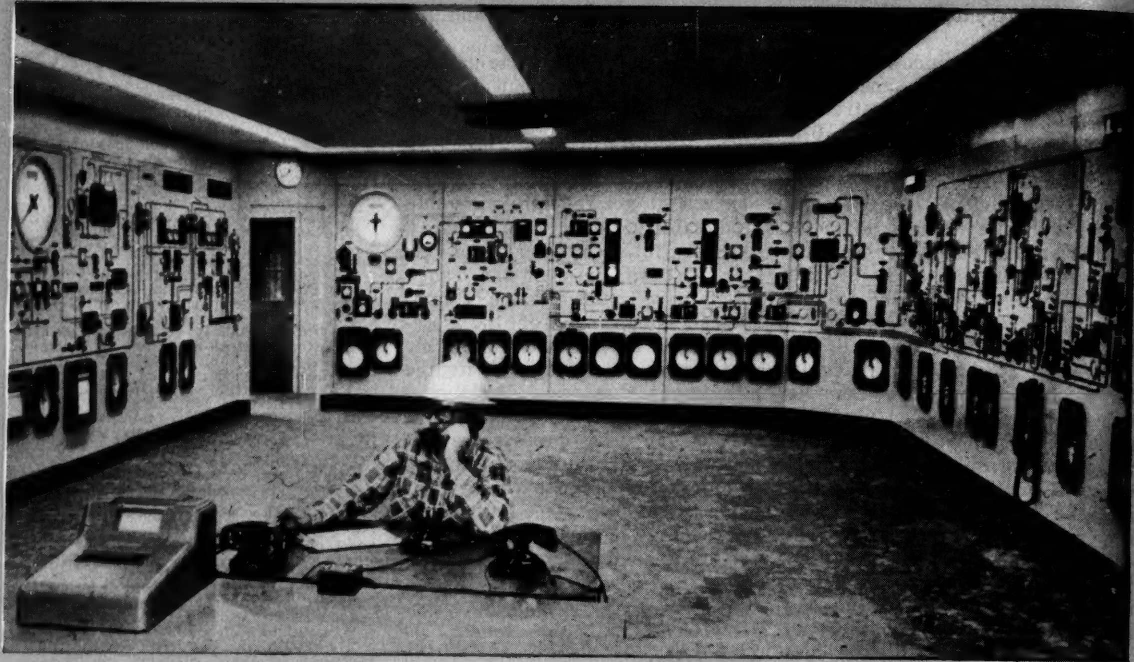


Cobalt neutron capture, gamma-ray spectrum. (Fig. 9)



Non-dispersive ultraviolet analyzer. (Applied Physics Corp., Fig. 10)



Conventional pneumatic control-room panel indicates, records and controls process variables. (Fig. 1)

Data Handling Systems

T. R. Vick Roy, E. I. du Pont de Nemours & Co., Inc.

Spread before your eyes in the illustrations above are two stages in the development of control rooms. On the left, you see the manifestation of two major developments: the centralized control room and the graphic panel. On the right in the foreground, is one of the first installations of data logging equipment, in the world's largest crude distillation unit.

Magazines have set forth the advantages offered by new data handling systems as seen by people interested in the manufacture of such equipment. From the standpoint of the user, application of these systems is in a very early stage. For that reason, we shall attempt here to look at the present state of equipment development and at the financial justification for its installation in process plants.

Present Practice

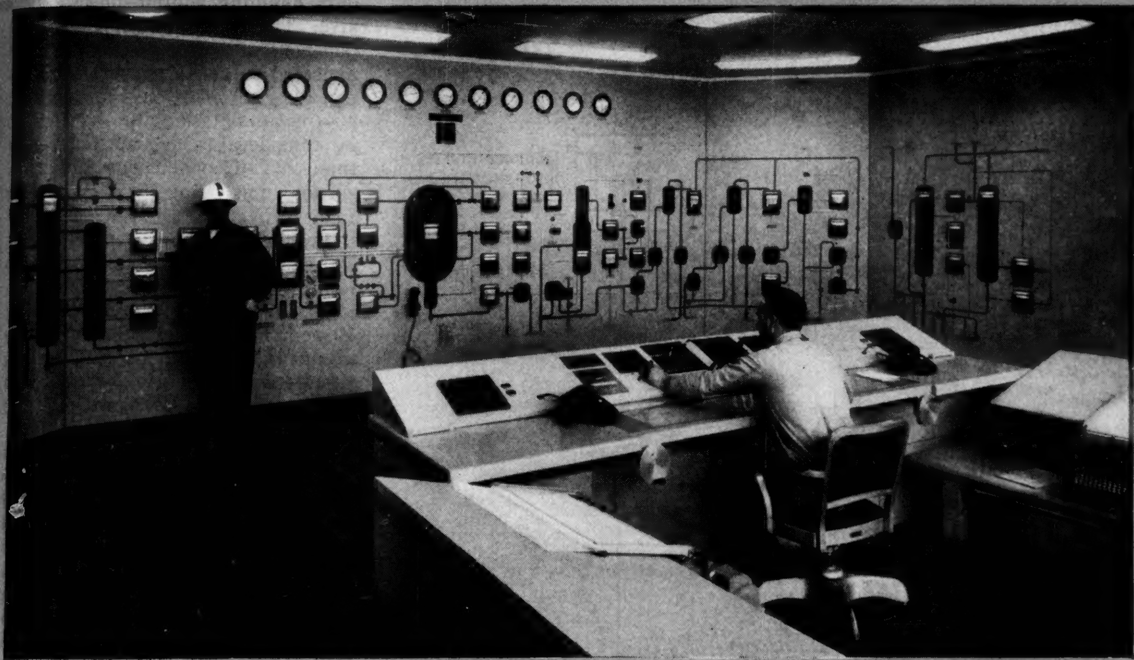
First, let us take a good look at present practices. Most of the instruments used to measure process variables in a modern chemical plant operate pneumatically. A block diagram of a typical installation using flow measurement and control is shown on Fig. 3.

Differential pressure across an orifice is measured by an instrument which transmits an air pressure signal to a controller and to a recorder located in a central control room. The controller, in turn, supplies an air-pressure signal to a pneumatically operated control valve. Instrument manufacturers have standardized on 3-15 psi. range of transmitted air pressures for all equipment, corresponding to the zero and the full scale reading of the instrument, respectively.

There are also several equivalent electronic process-control systems currently on the market. These are providing strong competition for pneumatic equipment and are taking an increasingly large share of the market. A typical system of this type is shown on Fig. 4.

Again, the differential pressure across an orifice is measured by an instrument, which in this case transmits an electrical signal to the recorder and controller. The controller, in turn, transmits an electrical signal to a power relay to operate a pilot valve which controls the air pressure supplied to the pneumatic control valve.

Considerable work is being done by manufacturers to develop inexpensive self-contained electrohydraulic valves to eliminate the need for compressed air distribution



Panel for Tidewater's Delaware crude distillation unit; logger records 500 points. (Fig. 2, Panellit, Inc.)

systems. But pneumatic valves will probably be with us for several years.

As yet, the manufacturers have not standardized on a standard transmitted signal comparable to the 3-15 psi. used in pneumatic equipment. As a result, one manufacturer's transmitter generally cannot be used with another's recorder.

There appears to be a trend toward eventual standardization on a d.c. current system, 1 to 5 ma., d.c., corresponding to the zero and full-scale reading at the instrument respectively. This has been adopted tentatively by several manufacturers.

Because of the increasing complexity of chemical plants and their control systems, graphic panels like those shown in the photograph are used to assist the operator. In a large plant, several operators are required around the clock to patrol the panels, noting abnormal operations, and taking corrective actions.

Important data are recorded continuously on round chart or strip chart instruments. In addition, the operator periodically records the readings of all instruments on a log sheet as an operating record.

Data from the log sheet, such as flow of material into and out of the plant, electric power consumption, steam consumption, etc., are later transmitted to the cost accountants. Other data are used by supervisory and technical personnel to compute yields, check efficiency of operation, and study methods for improving operation.

Data-Handling Systems

Much of the routine work of the operator in scanning various instruments on the panel and logging their readings can be done for him by automatic data-handling equipment. A block diagram of a data handling unit is shown on Fig. 5.

Process variables are measured by transmitting instruments, thermocouples, pH meters and continuous process stream analyzers. Transducers are required to convert some of the transmitted 3-15 psi. signals in this example, into suitable electrical signals which the data handling equipment can accept.

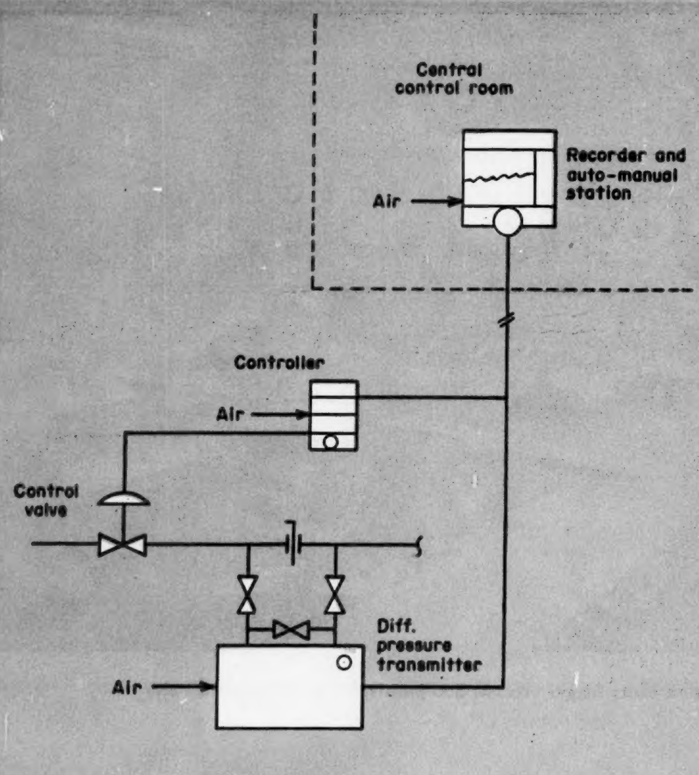
Some type of scanning switch is required for the sequential selection of the points to be measured. The input signal selected by the scanner is transmitted to the part of the circuit which measures the variable.

The measurement is coupled to an analog-to-digital converter which changes the measured analog signal to a binary coded digital signal. Finally, a translator of some sort may be required to provide the proper combination of open and closed circuits to operate the keys of an electric typewriter which is generally used for a logging device.

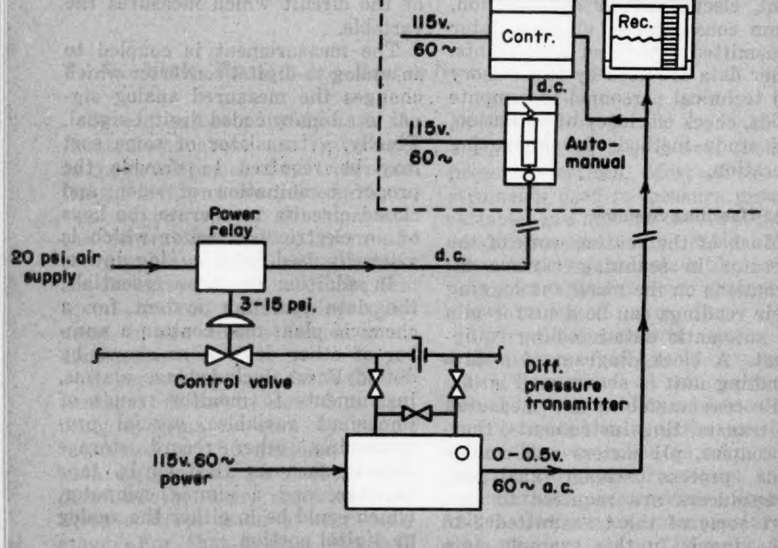
In addition to these essentials, the data handling system for a chemical plant may contain a number of other devices, as shown by dotted lines. Included are alarms, instruments to monitor trends of important variables, special programming, other record storage devices such as IBM cards, tape punches, and a simple computer, which could be in either the analog or digital portion.

Cost of Data Loggers

Next, let us examine the cost aspect of the problem. Automatic



Typical pneumatic flow control system. (Fig. 3)



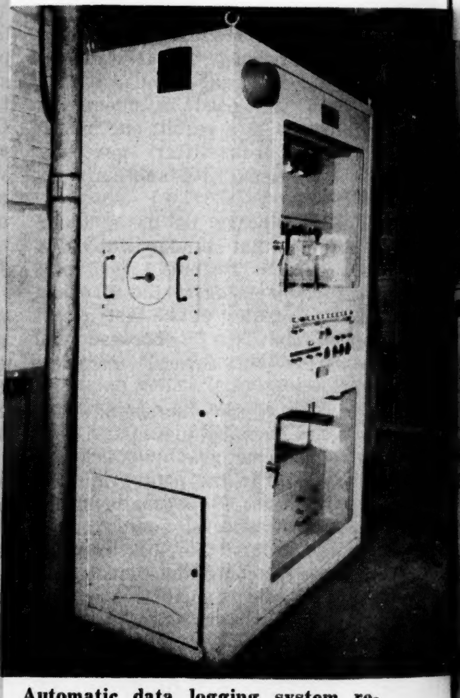
Electronic flow control with pneumatic control valve. (Fig. 4)

data handling equipment is expensive. The cost of such equipment depends, of course, on what it is expected to do. However, the purchase price of even the simplest automatic data-logging equipment is considerably higher currently than that of conventional chart recorders now being used in process industry.

Purchase costs are compared in Table I (p. 278). Price information on the data logger is based on competitive bids from approximately 10 companies for a system which is to accept approximately 200 input signals from a variety of sources such as 3-15 psi. transmitters and thermocouples.

The equipment must scan the variables at the rate of 5 points per sec., print out point numbers and readings of off-normal points, log all points approximately twice an hour, and also provide digital trend recording of any 16 points which the operator wishes to monitor. No computing functions are involved, other than integration of approximately 10 flows.

As the table indicates, use of an automatic data logger is expensive if it is used merely as a means of providing a record and actuating alarms.



Automatic data logging system records pressures, temperatures and

Justification

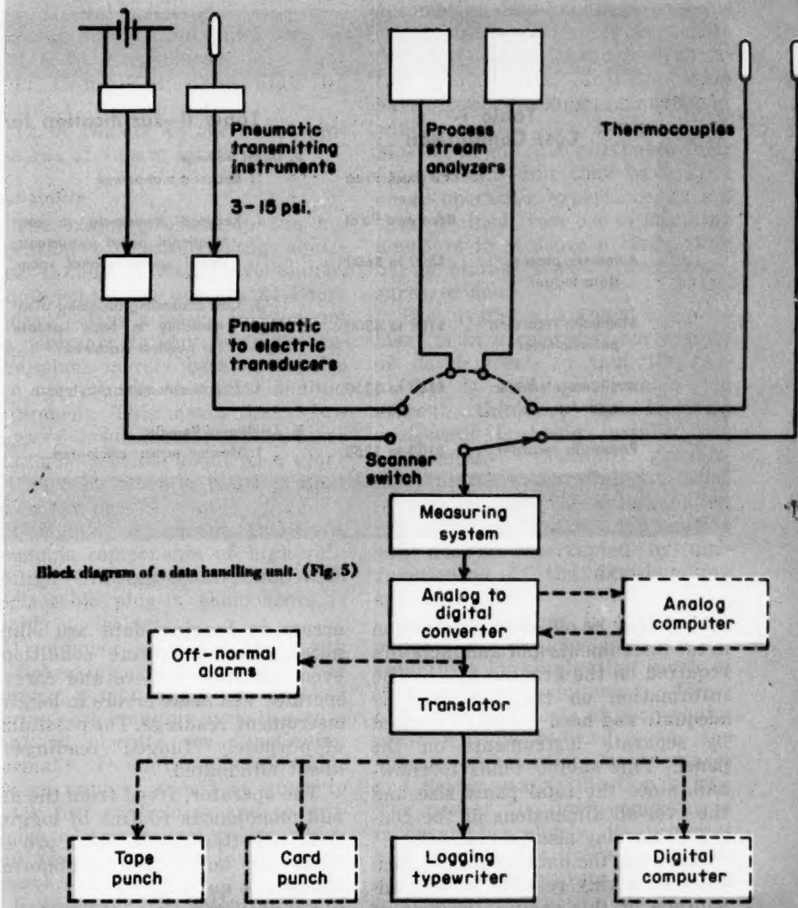
Management naturally asks, "What are the advantages of a data-logging system which justify the additional expenditure to record this information?" A number of justifications exist, some of which are outlined in Table II. They may be broken down into direct savings, which can be firmly estimated, and additional advantages of intangible value.

Direct Savings—Reduced operating manpower for a new plant is sometimes cited as a large potential saving. Actually, the saving from this source is not as great as might be hoped.

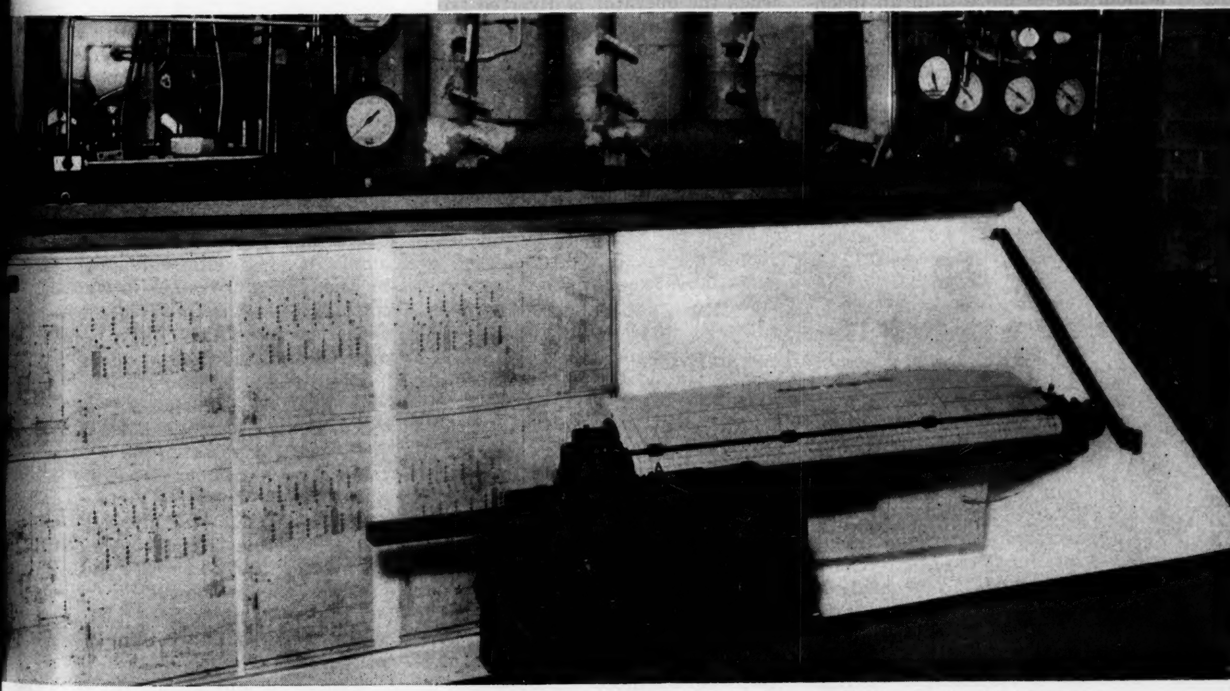
A modern chemical plant is largely automatically controlled. The operators spend relatively little of their time logging instrument readings. Much of their time is spent in patroling the plant and in correcting plant operating upsets that may occur.

In many cases, central control-room crews are already so small in size that further reductions do not appear feasible. The process must be relatively large and complex, involving about 300 to 400 logged variables for the data-handling system to relieve one operator.

Part of the cost of a data-logging



Block diagram of a data handling unit. (Fig. 5)



levels on catalytic reforming pilot plant of The Standard Oil Co. (Ohio). Logger (left) can handle inputs from three pilot plants, feed data to three typewriters such as one in cabinet (right). (Fig. 6, Fischer & Porter).

Table I—Cost Comparison

	Purchase Price per Recorded Point
Automatic process data logger	\$300 to \$600
Multipoint recording potentiometer	\$100 to \$200
Miniature electronic recorder	\$150 to \$250
Pneumatic recorder	\$100 to \$250

Table II—Justification for Automatic Data Logging

A. Direct Savings
1. Reduced manpower.
2. Reduced investment in conventional panel instruments, panel space, control room.
3. Cost accounting obtained automatically in form suitable for business machines.
4. Makes automatic calculations.

B. Additional Benefits
1. Human errors eliminated.
2. Operator freed from routine, better able to handle operating problems.
3. Records maintained during emergency when operator diverted from logging.
4. All variables logged at about same point in time.
5. Variables logged at shorter intervals providing more detailed data for technical studies.

system may be offset by a reduction in the instruments and annunciators required on the graphic panel. The information on the log sheet is adequate and need not be duplicated by separate instruments on the panel. This saving tends to snowball, since the total panel size and the over-all dimensions of the control room may also be reduced.

However, the data-logging system must be highly reliable to take advantage of this saving. Failure of one or two conventional instruments seldom causes more than an inconvenience, but failure of the logging system may force a plant shutdown if no duplicate instruments are provided for essential data.

Assuming complete reliability, the over-all saving from elimination of conventional instrumentation is in the range of 20 to 50% of the cost of the data-logging system. Only about one-fourth of this saving is attainable with present reliability. (The problem of reliability is discussed in more detail below).

Cost-accounting data may be obtained automatically in the form of cards or tape suitable for direct use in business machines. By this means, the cost of taking data from an operator's log sheet, transmitting it to the Accounting Department, and putting the data onto cards is eliminated.

Routine calculations which normally occupy the time of technical or clerical personnel can be made by machine methods, if the desired data are also recorded on punched cards or tape.

Intangible Advantages—Human errors in logging data are eliminated. Under routine conditions, even the most sincere and careful operator will make errors in logging instrument readings. The possibility of purposely "fudged" readings is about eliminated.

The operator, freed from the dull and monotonous routine of logging data, is better able to watch process conditions and to handle abnormal conditions quickly.

Reliable records are maintained even during emergency periods when the operator is diverted from logging. Data obtained during the emergency condition may be of great value in ascertaining the cause and preventing future recurrences.

Since the automatic logger records data much more rapidly than the operator, all variables can be recorded in 1 or 2 min. Compare this with 20 min. to an hour for the operator to accomplish the same job. Since all the variables are logged at about the same point in time, the data are of much greater significance in technical studies.

All the variables in the process can be logged at frequent intervals providing more detailed data for technical studies than could be obtained by manual logging methods.

Future Prospects

By tying the data-logging system directly into a computer for bookkeeping and technical computations, additional justifications appear.

Having data quickly available for management decisions, can have considerable value. Automatic handling of business information by means of punched card equipment has been common for many years. Linking such equipment at widely separated sales offices, plants, and executive offices by teletype wires is a more recent innovation.

Such methods permit rapid handling of customer orders at less clerical cost. Inventory, production rate, and cost information could also be fed automatically into the system from the plant data loggers.

Thus more complete and better digested data can be made available to management more quickly. Decisions on such matters as what production to schedule in view of sales and inventories can be made with more facts and with less reliance on sales forecasts, experience, and intuition.

Continuous calculations of process data can provide operating guides which are considerably more valuable than the raw data. For example, if yield data were available to the operator immediately, the combination of circumstances which caused a low yield might be recognized and corrected at once.

At present, computations of yields, power efficiency, steam efficiency, etc., are made hours or in some cases, days after the data are taken. Such calculations may indicate what happened and what corrective action should have been taken, but this is closing the barn door after the horse is gone. Increased chemical reaction yields alone might justify the entire cost of the data-handling system in some processes.

Simple computations involving

addition, subtraction, multiplication or division by a constant, and square-root extraction are available in data-logging equipment now in manufacture.

The computations usually are made in the analog portion of the system, using standard analog computer components and techniques. This method of computation appears the most economical for the usual chemical plant installation involving 100 to 500 scanned variables, 5 to 15% of which are used in computations.

The largest practical problem is accuracy of the measuring instruments. The process industries are accustomed to using instruments with errors in the order of ± 1% of full-scale range. When signals from several of these instruments are used in automatic computation, the resulting cumulative error can easily be in the order of ± 5% of the computed value.

The portion of this error caused by the computer is usually minor. Even with the best process instruments available today, with carefully engineered installations, and with good maintenance, it is difficult to get computed results of accuracy useful to the operator.

The addition of data-logging equipment is only one more step in the continued effort to bring necessary information immediately to the fingertips of the plant operator and to management. A composite of the ideas of several people portrays what the control room of the future might look like, Fig. 7. Some of the features are:

1. Recorders showing inventory, production, and yield data.
2. Trend recorders by which the operator may dial any measured variable in the plant and have the history of that point for the last four hours displayed graphically on the panel.
3. A scanner which indicates on a cathode-ray tube deviation from normal for a large number of variables.
4. A compact alarm-indicator panel consisting of a color television tube on which normal points are indicated in green and abnormal points in red.
5. A wired television system to enable the operator to view different locations in the plant, being scanned by cameras.
6. A miniature graphic panel with small switches which the operator may use to obtain a reading of any process variable on a digital indicator.
7. Digital indicator.
8. An automatic data logger.
9. & 10. A computer.
11. Computer programming boards.
12. A camera to record graphic records of future interest.

Reliability

The major problem in the application of data-handling equipment to chemical plants is reliability. Equipment must operate 24 hours a day, 7 days a week. It must not be necessary to shut down the entire plant merely because repairs are required in the data-handling equipment. This means that a few days of downtime for maintenance might be possible about once every six months when a plant is shut down for process reasons.

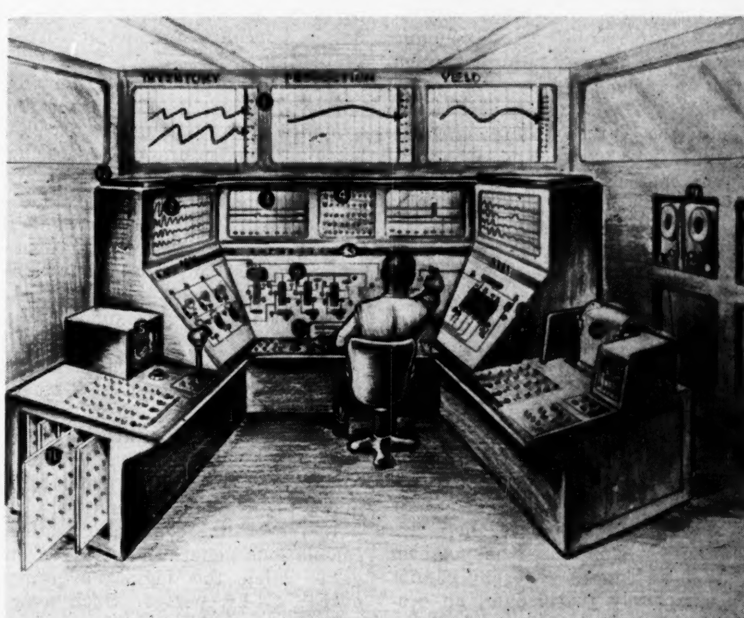
Design of equipment, therefore, demands components of high reliability. Unitized construction with replaceable plug-in components is highly desirable.

Equipment must be built with self-checking features, such as dummy points which are checked during each scanning cycle to assure that all circuits are functioning normally. In addition, considerable design thought should be given to quick test procedures and to provision of special test points which can readily be used for isolating troubles.

In summary, the potentialities of automatic data-handling systems are having considerable impact on design of new plants and modernization of old plants. Most companies have foward-looking management which realize its potentialities. Most of them have purchased their first system. But they have little or no operating experience, except that obtained from use of scanning monitors to measure a large number of similar temperatures, pressures, or flows.

The available automatic equipment is in a relatively early stage of development so that its reliability is still questionable. In present thinking, data-handling equipment is being installed experimentally. Standard graphic-panel instruments are being installed in parallel with the data-handling equipment so that plant operation will not be interrupted by malfunctioning of the data-handling system.

After reliability is proven, economies can be made in future installations by eliminating much of the duplicate equipment. Users hope also that costs of such equipment will be reduced when the volume of manufacture increases and design standardization exists. The use of "on-line" computation is developing slowly, its progress held back by the limited availability of more-accurate measuring instruments.



Control room of the future, based on ideas of several people, may look like this. (Fig. 7.)

Computers in Process Control

Arthur Frellich
Burroughs Corporation

Chemical engineers know how both analog and digital computers are used in process plants for engineering computations, simulation, operations research, scheduling, accounting and other "off-line" activities. But, so far, we've seen only the early stages of computers incorporated in real-time or "on-line" process-control loops.

To state definitely how we'll achieve computer control of a continuous chemical process is impossible at present. While experience gained in aircraft and missile work may indicate possible techniques, it cannot determine applicability of computers to process control owing to ever-present economic factors which are vital to industrial operations.

Although we can only guess about the future, there is little doubt that integration of computers in process control will be a gradual development. Most likely, it will progress as follows:

1. Use of digital data loggers.
2. "On-line" calculation of operating guides.
3. Computer supervision of processes.
4. Dynamic control of processes with computers.

Use of Digital Data Loggers

Data loggers which produce process data in digital form are being used today in a variety of process plants. Despite their advantages, experience has shown that data loggers generally cannot be completely justified on an economic basis in a process plant.

In Fig. 1, you see how information flows in a process that utilizes a graphic control panel system and a data logger. The process is controlled dynamically by the analog control loops running between the process and the control instruments. A secondary supervisory loop handles information from the instruments and data logger which the operator uses to change controller set points.

Both of these loops involve real-time operation with respect to the process. The operator bases his control decisions on the primary process variables such as temperatures, pressures, flows, levels and composition. Relying on past experience, he sets these variables to obtain a specified product at a fixed production rate.

On a long-term basis, accounting supervision of process operation provides data to define controller settings for minimum operating cost. Among the factors that accounting must consider are production scheduling, and secondary process characteristics or "operating guides" such as yields, efficiencies, heat and material balances, production rates and catalyst consumption.

Long-term supervision is not a real-time control. You cannot measure secondary operating guides directly by instrumentation. They must be calculated in an "off-line" computing center by combining many primary measurements.

In the off-line computing center, calculations generally are based on data which the logger averages over a 24-hr. period. Such averaging completely obscures how efficiency, production rates, yields and other secondary characteristics may vary from hour to hour.

Also, results are not available to the operator until 24 hr. or more after the conditions existed. This makes the data relatively useless for control purposes.

In at least two refineries, operating guides calculated off the line have been used by process engineers to second-guess the operators, who based their decisions on primary measurement data only. These experiments have shown that control decisions based on calculated operating guides could improve process performance.

Present developments point toward providing the operator with real-time operating guides for use in controlling the process. This will require that the data logger contain a mechanism to solve operating-guide equations. Progress in this direction will be the initial area for integrating computers into the process control loop.

On-Line Calculation of Guides

In Fig. 2, you see how information flows where an on-line digital computer calculates operating guides in real time for use by the operator.

Now, the operating guides are printed out at the same time that the digital values are logged for the primary variables. Production schedules are still fed back from off the line. But the operator can obtain complete data at all times on yields, efficiencies, material balances and other secondary characteristics of the process.

Inputs to the computer are digitized values of process variables produced by the data-scanning equipment which constitutes the basic logger system.

Although Fig. 2 is based on using a digital computer, either analog or digital techniques or combinations of both can be used. The calculating may be done by a computer or by computer elements in various portions of the logger.

Where a limited number of simple calculations is required, analog computing is preferred. As the calculations increase and become more complex, the digital computer becomes the more economical choice. That's because the digital computer is so fast that its services can be time-shared among the various inputs. A large number of complex calculations can thereby be performed without adding extra equipment.

The on-line computer supplies

information not available previously to the operator. With this information, he can adjust process conditions to reduce costs and increase profits whenever the process is not operating at consistently optimum conditions.

In this way, the on-line computer changes the status of data logging equipment from a fringe contributor to that of a direct source of process savings. This is especially true in continuous processes with large throughputs where a small but consistent rise in yield or quality can represent a large dollar saving.

There are many processes today which should benefit from this type of computing installation by being able to maintain consistently optimum conditions. Among these are processes which operate with fluctuations in secondary characteristics caused by small upsets; and processes with time-variant characteristics caused by factors such as fouling of heat exchanger tubes and deterioration of catalyst.

This year has already disclosed at least one installation—in the Belot refinery of Esso Standard Oil S. A., at Havana—where use of real-time secondary operating guides in catalytic cracking will be studied to determine improvement of operation.[1] In this installation, some 11 operating guides will be calculated every hour by an analog computer incorporated in a digital data logger.

The importance of this experimental installation will be to demonstrate the feasibility of this type of equipment. For example, it may not be possible to utilize the computer to full advantage now due to the inaccuracies inherent in many existing primary measuring devices. These inaccuracies will tend to obscure true variations in the computed data, unless the variations are significantly larger than the errors.

Also, it is quite probable that the computed data will not be used fully until the operator is more familiar with the secondary variables and their relation to the process. Most process engineers also lack knowledge in this area. Therefore, it is likely that full utilization of on-line computers will be preceded by a transition period during which experience will be gained in use of computed data.

Although the on-line computer is in the supervisory control loop, it does not control directly any part of the process. Rather, the operator examines the calculated data and then uses his judgment to reset the control instruments to better values. The ability of the operator to utilize the computed data discreetly is vital in applying this type of equipment to process operations today.

There are several reasons for this. First of all, despite advances in the art, computers do not at present possess the high degree of reliability required for continuous process installations operating 24 hr. a day for months on end.

Since the operator is interposed between the computer and the process, failure of a computer does not cause process shutdown. Should the computer fail, the process can keep operating with conditions controlled to the last optimum settings, rather than by fixed empirical settings.

Computer manufacturers constantly strive to increase equipment reliability. At present, however, the human element would still be needed even if computers were 100% reliable.

Process Supervision by Computer

Why does the human element have to be utilized? Can we not go directly from the computer to the control points of the instruments so that the computer can automatically supervise the process?

From the standpoint of hardware, we certainly can. Relatively minor developments could produce devices to link the computer to the control instrument set points.

The major drawback is that the exact relationships of primary variables to secondary process characteristics are understood clearly for very few processes today.

An installation in which the computer is linked directly to the control instruments to maintain optimum conditions automatically is shown in Fig. 3.

The computer receives signals from the process in the same fashion depicted in Fig. 2. However, primary output from the computer now resets the control instruments on the panel to maintain optimum process conditions.

What dictates how to vary the control point settings of the instruments? In Fig. 2, changes were made by the operator. In Fig. 3, the discretionary powers of the operator no longer are available. Instead, he now functions as the connecting link between the real-time operation and the off-line operation. Also, he is available for manual control, when required.

It is up to the computer to operate in a predetermined manner, resetting the controllers to maintain optimum conditions. Since a computer can operate only in accordance with its set program, the relationships between the primary variables and the secondary process characteristics must be well established. Only then can the computer be programmed to modify the primary variables for optimum operation despite changes in conditions.

Use of on-line logger-computers, illustrated in Fig. 2, will assist greatly in providing data needed to determine process relationships. Lack of knowledge, which is a strong deterrent to computer supervisory control today, will be overcome gradually with such assistance.

There are other factors also which must be considered. In many cases, for example, difficulties arise because process time constants are large; a lag of several hours is not unusual. Automatic optimization becomes a difficult control problem if unstable operation is to be avoided. At present, human judgment exercised in the control loop permits us to optimize gradually without the problems inherent in the closed-loop system.

In addition, automatic optimization will require fast, accurate analytical measurements to provide continuous data on endpoint conditions. These measurements can be obtained only through wider availability and application of onstream analyzers.

Primary measuring devices, particularly flowmeters, must become more accurate so that the computer can evaluate process behavior under small changes in conditions.

There are several approaches which hold promise for future application of process supervision by computers.

The first approach uses the computer as an equation solver. From the measured primary variables, the computer calculates the secondary characteristics or other control criteria. Then, it relates these factors in accordance with fixed mathematical expressions to determine the corrections for the controller settings. Primarily, this type of calculation solves sets of simultaneous equations which express the process relationships.

Either an analog or a digital computer could be utilized to mech-

anize such an approach. Since the process is controlled dynamically by the instruments, the optimization routine of the computer remains in the secondary supervisory control loop and places no heavy time burden on the computer operation. This permits time-sharing (use in sequence on several operations) without need for high-speed computing.

The digital computer can time-share almost all its components among the various channels. For that reason, where there are many variables, the digital computer possesses an economic advantage.

When the computer is used as an equation solver, the relationships of the process must be established clearly. Therefore, before the technique can be applied, the process must be studied with care.

In one process involving batch hydrogenation, 25 graduate students at Case Institute of Technology devoted about 2 yr. of experimental study to determining system characteristics and relationships.[2] Then, with an analog computer optimizing on real-time, they reduced batch time 33% and cut composition variation between batches from 2% to ½%.

Another approach to optimization utilizes the computer as an automatic and efficient experimenter. (See p. 284—Ed.) The computer receives primary measurements, calculates secondary characteristics, changes one or more primary variables to determine how the changes affect secondary characteristics and continues this procedure until optimum conditions are attained.

Where more than two variables are involved in this procedure of "bumping" the process, choice of the computer is restricted almost completely to the digital type. That's because the experimental procedures become complex, and must be varied according to the previous results. Then too, this type time-shares its components.

However, as we mentioned previously, the time constants of many processes are measured in hours. This seriously impairs the bumping technique since the results of a single perturbation may not be felt for several hours.

To circumvent this difficulty, it may be necessary to include a simulation of the process in the supervisory control loop. Through this method, steady-state relationships of the process can be duplicated without the process lags.

Then, the computer would experiment with the process simulation to determine what are the best adjustments to make on the process. Periodically, the optimum set point changes would be transferred automatically to the process controllers. Before repeating the cycle, steady-state conditions of the simulator would be corrected to correspond to the actual process conditions.

Dynamic Control With Computers

A process may be controlled dynamically by the control instruments which monitor each channel, as shown in Fig. 3. The computer merely supervises these instruments just as the operator does today.

It is not unreasonable to consider the possibility of eliminating the individual controllers and incorporating the dynamic control in a digital computer to be time-shared among all the control loops. Such a system is shown schematically in Fig. 4.

This means that a single digital computer, operating on only one process variable at a time, can perform completely different control operations on each channel and yet utilize the same computing elements. Hence, use of a digital computer as a dynamic process controller can be justified economically by its ability to be time-shared, with related benefits in reduced instrumentation costs and control room size.

There are applications for this type of computer control today in areas outside the process industries. They are found where the control problem is so complex as to require a digital computer, and where control flexibility, accuracy and reduced size are primary considerations, rather than economic justification.

As shown in Fig. 4, the computer is in the primary control loop. It receives the measurements of process variables and positions the valves and other final control

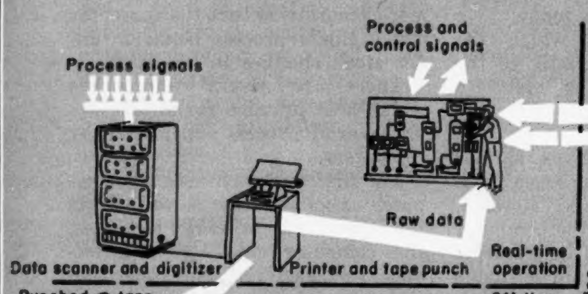


Fig. 1

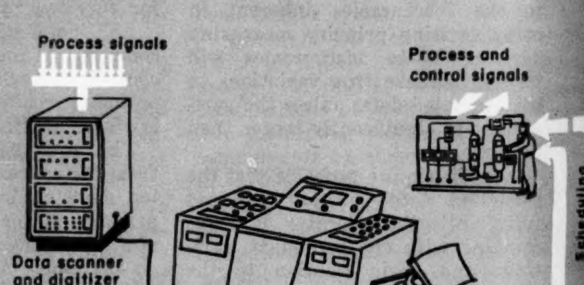


Fig. 2

elements directly. Proper hardware for linking the computer to the process is not yet available, but developments can be expected in this area.

One type of device that will be required for this linking is the digital transducer which can convert process variables accurately to digital values for input to the computer. Another needed class includes digital control elements, such as valve operators, which will control in accordance with the digital output of the computer. And, as in supervisory control with a computer, a need will exist for suitable on-stream analyzers.

Since the computer will operate on one control loop at a time, its speed in covering all the control loops will be important. One possible approach is for the computer to operate at speeds high enough so that each channel will be sampled and controlled at extremely short intervals, perhaps several times a second.

This procedure approximates continuous control on each channel because the time constants of most control loops are slow compared to the high operating speeds of digital computers. The digital computer then would solve essentially the same equations representing proportional, reset and derivative (rate) control modes as do the conventional instruments today.

It is possible to attain a great deal of control flexibility with the digital computer, even though the unit is solving basic instrument-control equations. For example, measurements of different process variables can be combined to determine the required control action.

To control a process with a large dead-time, it is customary today to incorporate proportional, reset and rate action, based on the deviation of the controlled variable. Rate action compensates for the deadtime by over-correcting, according to the rate of change of the controlled variable.

With the digital computer, the controlled variable deviation would still be the basis for proportional and reset action. But the rate action could be based upon another measured variable which changes before the effect is felt at the controlled variable. Thus, the controller would truly anticipate a change rather than to rely on rate action which approximates the anticipatory correction.

Obviously, as the number of variables to be controlled increases, computer speed must be increased if the unit is to approximate continuous control on each channel. This increases the cost and complexity of the computer so that its use becomes more difficult to justify economically. As a result, efforts must be made to reduce the required computer speed, without sacrificing the quality of control.

If the computer is used to solve the normal equation for proportional control, the same width of proportional band can be used as in a conventional instrument. But, for practical purposes, the sampling rate on that channel must approach continuous control.

If the computer's sampling rate is reduced so that changes in control action are in fact intermittent, it will be necessary to use a wider proportional band to achieve stability. Widening the band results in slower recovery time and, therefore, degradation of control.

In the case where the computer samples slowly, new modes of control based on intermittent sampling rather than continuous measurement will have to be used. For example, a possible solution to the need for a wider proportional band is to program a non-linear proportional action. This would produce a wide band or gradual correction near the control point, and a narrow band or large correction when the deviation from the control point increases. This would be done easily with a digital computer.

To determine the required type of control action, the dynamic characteristics of the process must be established. In the past, this has called for disturbing the process deliberately in order to study these characteristics. But such disturbances generally are prohibited in a process plant.

Now, however, techniques are being developed which permit the engineer to determine dynamic responses of processes with either extremely slight process fluctuations or without any externally in-

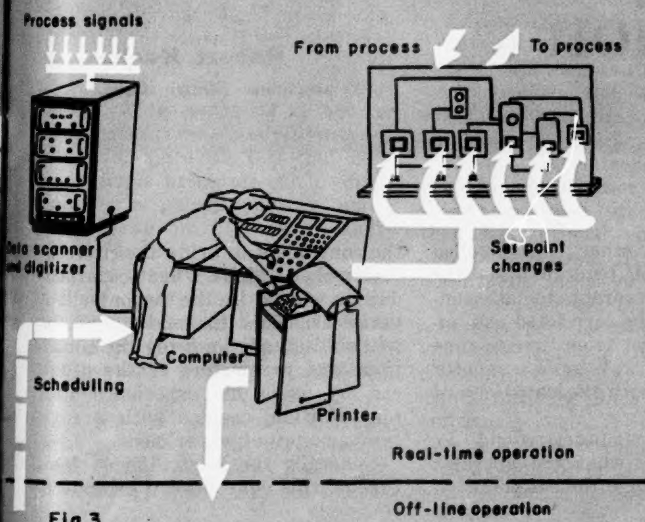


Fig.3

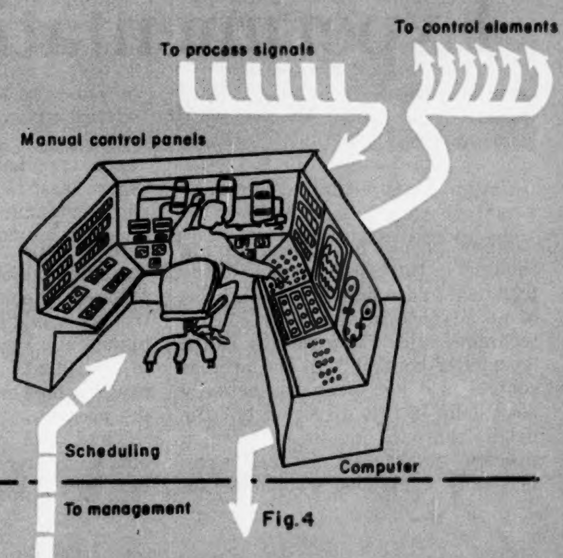


Fig.4

troduced disturbances. One notable technique in this category is the cross- and auto-correlation study. By mathematically analyzing random variations which normally are present in a process, this technique makes it possible to define the dynamic characteristics of process loops without disturbing the process.[3]

Much work is being done in the areas of sampled data systems and determination of system characteristics. It appears that a practical compromise may be possible in many cases to produce improved dynamic control with a digital computer without need for extremely high speed.

It has even been suggested that in the future, auto- and cross-correlation might possibly be used by the computer-controller to redetermine continuously the system characteristics. Then, computer control functions could be adjusted to conform to changes in plant dynamic responses caused by time-varying factors or system non-linearities.[4]

When are we likely to see digital computers utilized for dynamic control of a continuous process?

Dynamic control requires that the computer operate in the primary control loop. Computer failure means process shutdown. As a result, the reliability of the computer must be as good or better than the reliability of major process equipment.

Certainly, until such reliability is available without increasing computer cost excessively, we cannot expect general use of computers for dynamic process control. Despite advances being made today, it is doubtful whether the necessary reliability will be available for several years.

Since optimization will also be part of the control computer's job, use of the computer for dynamic control cannot be expected to precede the general use of computer optimization. Add to these factors the need for accurate digital primary measuring devices and control elements, and more on-line analyzers. The total requirement indicates that dynamic computer control in the process industries in general is approximately ten years in the future.

A still later step in utilizing computers could involve over-all supervision of plant or company operations by a central digital computer. This, in turn, could control smaller computers operating in various plant areas—the widely discussed automatic-factory concept.

Whether or not this concept is valid for a chemical process plant is open to some question at present. In any case, we can be sure that a long evolutionary development will be required before any such concept can be considered practical. However, we appear to be at the beginning of this evolution today.

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3. Goodman, T. P., and J. B. Reswick, *Trans. ASME*, Feb. 1956.
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Control by Automatic Experimentation

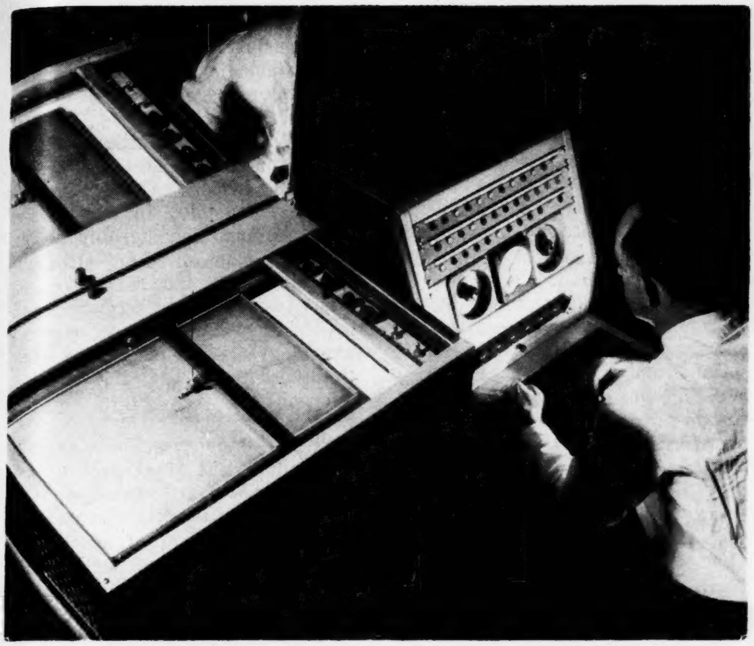
In correlating his various controllers the plant operator experiments with various settings. It is possible to develop computer-controllers which operate similarly, though faster and more accurately, to optimize control.

Robert Hooke
Westinghouse Electric Corp.

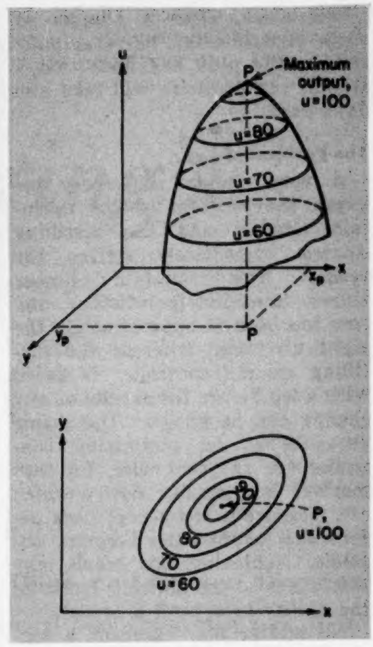
Many people have been giving thought in the last few years to the technical and economic possibilities of an advance in automatic control technique which is generally called "computer control." In the process control field not much has actually been done in this direction but the usual approach is to envision a process embracing several automatically controlled variables, together with other uncontrolled variables which tend to upset the process. The several automatic controllers would be correlated and automatically reset from time to time in the "best" way by a computer programmed with the equations of the process.

Thus, the computer would do, but do better, what the operator now does—change the set-points of the controllers to bring the process back when "drift" had occurred due to shifts in the uncontrolled variables. This the operator does without actually knowing the equations and parameters of the process, by using his experience and his intuition, coupled with a certain amount of experiment.

Generally the most difficult feature of this conventional computer



Automex controller, operated by Author Hooke, was demonstrated by simulating a mountain climbing problem, using a contour map on the plotting board.



Graph of surface $u = f(x, y)$. (Fig. 1) Contour lines of same surface. (Fig. 2)

approach is to discover the process' equations and parameters. Ordinarily they are not known and are extremely difficult to uncover except in simple processes. On this account, several investigators have independently adopted another approach which stems from the methods of the human operator—to experiment automatically with the settings of the various controllers and to continue resetting in approximately the best direction until an optimum result is achieved.

The author's approach, which has resulted in the Westinghouse "Automex" controller, provides an automatic experimenter which is expected to be able to solve control problems in several broad categories. This controller is not on the market as a ready-to-use instrument, since we feel that only very simple processes can be handled by a general-purpose logic. Even these might require individual planning.

In its present stage of development the "Automex" solves a fairly general problem of automatic control which involves the optimizing of the output u in the expression:

$$u = f(x_1, x_2, \ldots, x_n; z) \qquad (1)$$

Here the x's represent controlled input variables, while z represents a collection of variables which, for one reason or another, are uncontrolled. In the special case where there are two controlled input variables, x and y, the equation can be written:

$$u = f(x, y; z) \qquad (2)$$

This might be pictured graphically as a surface in three dimensions, as in Fig. 1, or as its equivalent in the form of contour lines, as in Fig. 2. To bring this type of situation down to cases, the problem might be that of controlling a distilling column where:

$$u = f(P, T; z) \qquad (3)$$

Here u is the overhead product purity, which is to be maximized. It is seen to be a function of pressure P and temperature T, which are controlled, and of certain uncontrolled variables z, chiefly the entering composition.

If the uncontrolled variables could be kept fixed or at least made to change in a predictable way, then conventional computer control could be used. However, this is not usually the case. The only recourse in the past has been to use a human operator who, although he knows little about the underlying relations of the process, experiments until he finds the current optimum.

In a simple regulatory problem such as that of house temperature control, which is readily solved with an inexpensive thermostat, there would be no point in going to any of the various forms of computer control. In the usual optimizing problem, however, the situation is totally non-linear. That is, when changes in the uncontrolled variables z cause drift in the process, there is in general no way to tell which inputs should be changed, nor in what direction, to compensate for the changes in z which caused a drop in μ. The control must then proceed by intelligent trial and error. It must make small experimental changes, observing the results and learning from the observations how to go to the optimum combination of input settings. In the distillation problem it would make changes in T and P and note the effect of these changes on the output composition u.

A simple example of an optimizing problem of this sort is illustrated by a mountain climber who attempts to scale a peak in complete darkness. He cannot see where he is going but he is able to tell whether he is going up, down, or horizontally. The criterion of a successful step is that it take him up the slope. If a step is thus successful, he takes another in the same direction. If it is not, he tries another direction. His personal optimizing problem will have been

solved when, after a number of such experiments, he eventually reaches the peak and finds that a step in any direction will take him downward.

The Problem of Lag

A very obvious difference between the problem of the mountain climber and the distilling column immediately strikes the reader. The mountain climber knows immediately whether any step has been in approximately the right direction, whereas the distilling column controller is faced with a lag before the results of any change can be known. The prime requisite of an optimizing controller (or any controller, for that matter) is a sensing device which can measure u and report back before the information becomes obsolete. Achieving this result may sometimes be the limiting factor in the ability to control a process.

No matter how excellent a controller's logic may be, it will be ineffective unless the information on which it operates is received in time. Here, time is relative. The report on the effect of changing the settings for one or more inputs may be fast or slow, but what counts is the relation between time to report, and the rate of drift in u caused by the changes in z. Suppose that the observational lag is 1 min. Then if the effect of variations in z is usually negligible in a 10-min. period, we can take 10 observations before the first one becomes obsolete. Probably the process can be controlled. But if strong effects of changes in z can occur every minute, then the process can be controlled only if the observational lag can be much reduced. Thus the actual units of time are unimportant, the crucial factor being the number of observations that can be made in a time during which the effect of changes in z will usually be negligible.

In cases where the observation response is very rapid, changes being observed almost instantaneously, quite a simple controller is possible and the "Automex" would not be needed. Instead, this device is designed for more difficult cases of optimizing where a fairly small number of observations must form the basis of decision.

The author's point of view, as expressed here, is that of the mathematician and experimental statistician, rather than that of the engineer, the latter generally preferring to express the drift or transient changes in the process in a functional fashion, however unlike the real situation the resulting mathematical description may be. The problem is very similar to that of finding the point of maximum output in the design of experiments. Although there is still much to be learned about such problems, certain generalities are known which greatly assist the procedure for maximum finding.

Specifically, our problem here is to replace a human operator who may be able to control the process satisfactorily, if not brilliantly. When he observes a drift from optimum output he begins to experiment, acting as if the process were stationary (no further change in z). Only when he notes a subsequent drift does he start further adjustments. By this time the observations he made before the last change have become obsolete, but he is usually protected from using this obsolete information because his memory is too short.

Carrying this idea over to the optimizing controller, it seems necessary only to find an intelligent search procedure which works on an unchanging function, then equip it with a memory which is neither too long nor too short. The controller must be able to recognize when a change has taken place so that it can start a new series of changes in the input settings, as well as observations of the results.

The Problem of "Interactions"

Also, arguing from the theory of the design of experiments, the controller must recognize the "interactions" between input variables. Consider a function of two independent variables:

$$u = g(x, y) \qquad (4)$$

It is generally true that the effect of a change in x (holding y constant) depends on the value at which y is held constant. When this is so, x and y are said to interact, which simply means that the function cannot be separated into two parts, as:

$$u = g_1(x) + g_2(y) \qquad (5)$$

Although it is generally recognized that most functions of the form of Eq. (4) cannot be expressed in the form of Eq. (5), there is still a great deal of experimentation in the engineering sciences which is done by the classical method of changing one variable while holding all others constant. This method is slow and sometimes fails altogether. Instead, for more efficient experimentation, it seems obvious that some observations must be made after changing two or more variables simultaneously.

The "Automex" operates in this way, although its logic has been kept quite simple to make it economically feasible. In most cases it can perform considerably better than a human operator, although it does not have the human operator's general adaptability and therefore will probably require some degree of redesign for each application.

How the Problem Is Solved

While it is not possible to explain in detail in this short article just how the "Automex" works, the preceding discussion has given the clue to its method of intelligent searching. Going back to the distillation column problem (Eq. 3), when the controller's sensing device reports a drop in u, it immediately begins a series of small changes in T and/or in P, waiting after each until the effect on u can be reported back. It continues making such changes until u increases to some maximum, which is followed by decreases in u in several directions of change. This shows that the combination of T and P which produced this maximum is the best obtainable. Ordinarily only a comparatively few tests will be needed to produce a maximum value of u at which further experiments will produce only a decrease. This then is the current optimum for the process.

Since this optimum will change with changes in the uncontrolled variables, the instrument will either keep up its searching, or stop and wait until a decrease in u indicates that searching should be resumed, depending on which course seems best from a prior knowledge of the process.

Various newer branches of mathematics and statistics, which have not been included in the classical engineering curriculums, deal with the problem of maximum-seeking. (See, for example, M. M. Flood, "New Mathematical Tools for Decision-Making," *Industrial Laboratories*, Sept. 1956.) Much research is going on in these fields and eventually will have important effects in certain areas of automatic control. It seems clear that there are areas where those who insist on formulating all problems in terms of differential equations will be left behind.

Chemical Engineering's Guide to Process Instrument Elements

Theodore R. Olive and Steven Danatos

***Chemical Engineering,* New York, N. Y.**

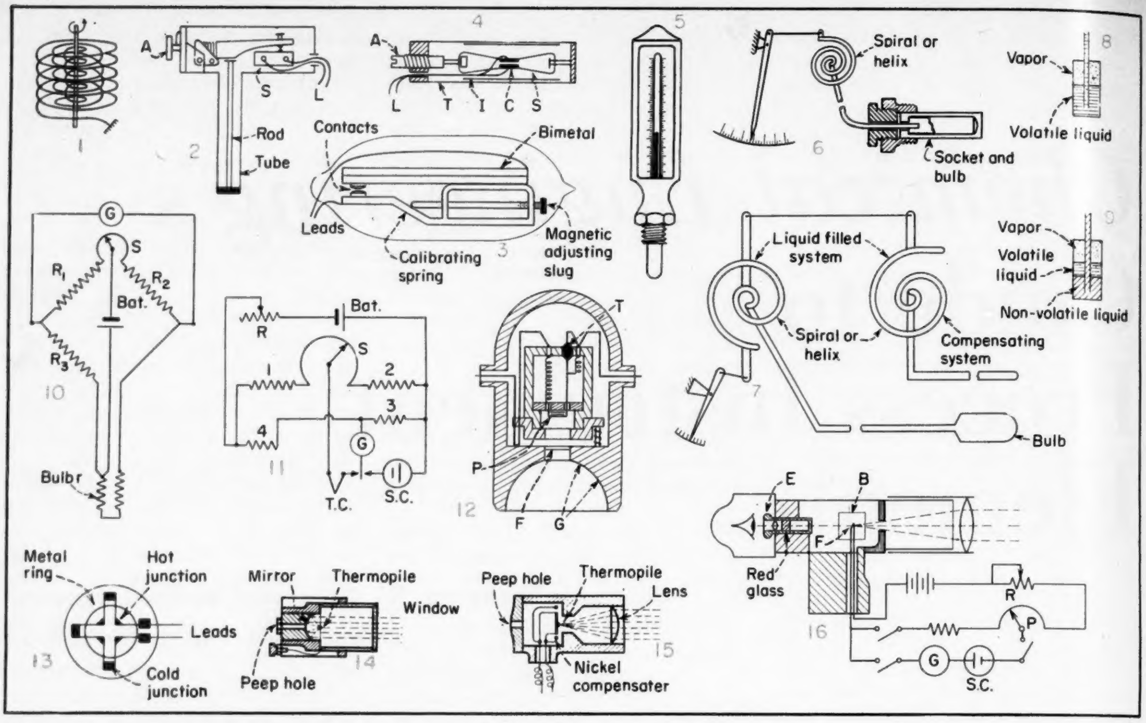
Reason for This Guide

In 34 pages this guide attempts to compress in one place the greatest possible amount of information on process instrumentation for use in preliminary selection. It is an extensive revision and enlargement of the similar guide which appeared as part of our May 1952 issue. It is not intended as a substitute for the literature, for manufacturers' catalogs, nor for their recommendations.

The guide is organized in the 27 sections listed at the right, the first 22 being mainly concerned with process variables and their measurement. The remaining sections deal with measuring devices, transmitters and telemeters, controllers and final control elements.

Many sources have contributed to this guide, including users, manufacturers and the literature. Members of the instrument industry who supplied information are listed on p. 320.

Its Contents



Figs. 1-16—Temperature measuring instruments including thermometers and pyrometers.

1 — Temperature

Principle	*Range*	*Accuracy* *	*Applications and Remarks*
(a) Differential Expansion			
Fig. 1—(Weston) High-expansion metal strip welded to low-expansion strip deflects on temperature change. Multiple layer helix tends to cancel endwise motion and leave only rotary motion when element is heated. Extra large deflection can be obtained by "coils-in-coils" construction.	−40 to 800° F.	Up to 1%.	Simple, rugged, relatively accurate for temperature indication, interchangeable with glass industrial thermometers.
Fig. 2—(Burling Inst. Co.) Bimetallic contact-making thermostat has low-expansion rod in high-expansion tube which moves arm to depress switch S controlling circuit L. Set-point changed by A which moves pivot point of arm.	Sub-zero to 1,800° F.	Minimum differential ¼° F.	General temperature control using electric circuit, but can be supplied with air pilot. Rugged construction, steady control, readily set control point.
Fig. 3—(Edison) Bimetallic thermostat, hermetically sealed in glass tube which may be gas-filled. Thermostat calibrated after sealing by means of magnetic adjusting slug.	−10 to 600F.	±4.5° F.	Continuous duty with no change in operating temperature. Limited to 1,000 watts maximum load.
Fig. 4—(Fenwall, Inc.) Bimetallic contact-making thermostat has low-expansion struts S carrying contacts C in high-expansion tube T. Break-point regulated by temperature-set screw A. Opens or closes on less than 0.5° F. change.	−100 to 1,500° F.	Differential less than 0.5° F.	General temperature control using electric circuit. Fast reaction time, low differential, enclosed assembly. Insulation I gives anticipatory action.
(b) Fluid Expansion			
Fig. 5—Industrial thermometers use volumetric expansion of mercury or an organic liquid such as alcohol, in non-etched glass capillary. Nitrogen fill can increase top temperature.	−38 to 675° F. (Hg), lower for organics, higher for nitrogen.	Approx. 1%.	Widely used for temperatures where a record is not needed. Case protects capillary, scale readable at distance.
Fig. 6—Class I liquid filled thermal thermometer uses organic liquid fill in bulb connected by capillary to pressure spiral or helix (like pressure gage). Class V is similar system but uses mercury for fill. Temperature changes at bulb distort pressure element to indicate on scale. Over about 25 ft. of capillary, thermometers require ambient temperature compensation. Full compensation is obtained by second thermal system (no bulb) as in Fig. 7 or, if mercury filled, by special alloy wire in capillary.	−200 to 1,000F. with various fills.	½ to 1%	Gives uniform scale with equal accuracy at all parts of scale. Uses small bulb. Can be supplied with short span. Capillary error compensation good for 200 ft. or more. Can be case compensated with bimetallic compensator attached to pressure helix. Used for indicating, recording and controlling.
Fig. 8, 9—Class II filled system thermometer operates on vapor pressure of a volatile liquid in bulb. Interface must be in bulb, with capillary filled with the liquid (except for bulb temperatures below ambient, when capillary is vapor filled). Single-fill type (Fig. 8) may lose interface. Double-fill type (Fig. 9 Bristol) has non-volatile transmitting liquid, interface remains in bulb at all times.	−300 to 600F.; 200° F. top for double-filled.	½ to 1%.	Gives high response speed, non-uniform scale; permits up to about 200 ft. of capillary without compensation. Must be calibrated for head of bulb above or below pressure element. General use for indicating, recording and controlling.
Class III filled system thermometer has gas fill under pressure in bulb-capillary-pressure element system. Expansion of gas distorts pressure element, giving uniform scale.	−460 to 1,000F.	½ to 1%.	Has comparatively large bulb. Ambient errors small up to 200 ft. capillary, thus needing no compensation.
(c) Resistance Thermometers			
General: All forms of resistance thermometers operate by measuring in terms of temperature the resistance of an element which varies with temperature. Measurement is ordinarily accomplished with some form of wheatstone bridge circuit.			

* *ACCURACY— Unless otherwise stated, figures for accuracy given here as percent mean that the average expected error will not be more than plus or minus that percentage of full instrument scale. Accuracy figures are difficult to obtain for many kinds of instruments. In a few cases the figures have been estimated from best available data. It should be understood that these figures are rough and that well designed instruments, well installed and maintained, may give considerably better accuracy, while poorer results may be obtained if the reverse is true.*

1—Temperature (Cont.)

Principle	*Range*	*Acc'y (p. 285)*	*Applications and Remarks*
Fig. 10—Resistance thermometers are usually a coil of fine wire such as platinum, copper or nickel, wound on an insulating frame, ordinarily protected. To cancel out effect of variable lead resistance three-wire lead system is used.	−325 to 1,200° F.	0.25 to 1%.	Used for temperature, temperature difference and temperature averaging. Quick response, small spans possible. Can be used for highest precision.
A fine-wire resistance thermometer (A. C. Ruge Associates), about the size of a postage stamp, mounted in paper, phenolic resin or silicone glass. Cemented to surface to be measured.	−100 to 500F.		Intimate bonding of resistance element to surface of object produces rapid response to temperature change.
Thermistors. (Gulton Industries, others). These are semiconductors which decrease in resistance with temperature. Can be used for very narrow spans, i.e., 4° F.	−65 to 150° F.		Potentially more accurate than thermocouples or resistance thermometers. Can be used as a thermocouple compensator.

(d) Thermoelectric Pyrometers

General: Thermocouples (thermoelectric pyrometers) operate on the Seebeck effect. When two wires of dissimilar metals are jointed at the ends and the junctions maintained at different temperatures, a current flows due to absorption of heat at hot junction. Voltage produced, which is proportional to difference of hot and cold junction temperatures, is measured either by a millivoltmeter or a potentiometer calibrated in terms of temperature of the hot junction for a fixed or compensated cold junction temperature. For potentiometers see Fig. 11 and Section 24.

Cold junction corrections. Since temperature measured by hot junction depends on a constant cold junction temperature, it is customary to bring the cold junction to the instrument case by use of compensating leads (same metals if base metal couple is used, or metals with similar thermoelectric characteristics if Pt is used). In the instrument, variations are compensated by bimetal, or nickel shunt across leads.

Noble-metal couples. Made of platinum and a Pt-10% Rh alloy or Pt-13% Rh alloy for highest temperatures. Top temp. depends on wire gage. Ordinarily requires protection.	Top temperature 2,700 F. for continuous use.	0.25%	Used for high temperatures, and as a standard instrument for calibration.
Base metal couples. Three types generally used, ordinarily with protection if in higher temperature ranges. (1) Copper-constantan, top temperature 700° F. depending on wire gage; (2) Iron-constantan, top temperature 1,400 F.; (3) Chromel-alumel, top temperature 2,300 F.	−200° F. to temps. noted.	Generally about 0.3 to 0.8% depending on span.	Give much higher millivoltage than Pt couples, although slightly lower accuracy. Used for same temperature range as Class I, II, V filled system type thermometers, as well as above and below.
Fig. 13—Special thermocouples. These include the thermopile (Fig. 13, a group of thermocouples in series) which multiplies voltage by number of couples; and vacuum thermocouple in which protection is afforded by sealing in evacuated glass.			Used mainly as radiation receivers in radiation pyrometers and special uses where speed or high response is needed.
(e) Radiation Pyrometers			
Fixed-focus type. Any radiating black body gives off total radiation that depends only on the temperature. An actual body can be corrected for departure from blackbody conditions. If radiation from a definite area is focussed on a thermocouple, the indicated temperature is proportional to the actual. Receipt of radiation can be made independent of distance without focussing by installing couple at base of long tube containing a conical and a spherical mirror.	200 F. and up.		No theoretical upper temperature limit. Needs no contact with object measured. Can measure temperature of moving objects. Records on millivoltmeter or potentiometer. Readily portable, since focussing is not needed.
Fig. 12—The equivalent of a uniform temperature enclosure is obtained by use of a gold-plated concave reflector G. Radiation approximating surface temperature is transmitted through fluorite window F and is measured by thermopile P. Ambient temperature compensation is provided by thermistor T. (Fielden).	100 to 2,400 F.	−1 to 0.5% depending on emissivity.	Portable instrument for spot readings on surface of opaque bodies. Pyrometer measures temperature 1/16 to 3/16 in. below surface because uniform temperature region forms under reflector G.
Fig. 14, 15—Focussing types. Similar in principle to fixed-focus type except that a mirror (Fig. 14) or a lens (Fig. 15) is used for focussing radiation onto a thermopile. Hence these types are used for permanent installations.	200 F. and up.		Gives extremely fast response, on fixed or moving objects, at temperatures above range of non-radiation methods.
(f) Optical Pyrometers			
Fig. 16—Disappearing filament type (Leeds & Northrup). Uses monochromatic radiation (rather than total radiation), determining intensity in comparison with a heated filament F which disappears at corresponding temperature. Filament current is measured in terms of hot object temperature. Filament viewed at E.	1,000 to 5,000 F.	About 5° F.	Manually operated instrument used for indicating, not recording high temperatures. Flat filament lamp B has parallel windows.
Optical wedge type. Similar to disappearing filament type except that target illuminated from calibrated lamp at standard current disappears as source intensity is varied by absorption in optical wedge. Wedge position calibrated as temp.	1,400 to 3,700 F. Special, 7,500 F.		Manually operated instrument used for indicating, not recording high temperatures. Any high temperature use where hot object can be sighted.

(g) Change of State

Melting point method. Melting points of pure solids used for thermometer calibration. Also boiling points of pure liquids.

Pyrometric cones. Calibrated ceramic mixtures molded as cones available to permit estimation of time-temperature history of fired charge. Used in ceramic manufacture.

Fusible crayon (Tempil Corp.). Fusible crayons, each covering a short range of temperature, can be marked on hot objects to show temperature by fusing. Color change paints are available also, some reversible.

2—Pressure

Principle	*Range*	*Acc'y (p. 288)*	*Applications and Remarks*
(a) Absolute Pressure			
Fig. 17—Liquid column barometer. The fundamental instrument for measuring pressure of the atmosphere. Glass tube, closed at one end and filled with mercury, is inverted in a vessel of mercury. Height of Hg column above vessel level is the barometric pressure in mm. Hg (corrected to mercury density at 32 F.).	Any pressure of atmosphere.	Roughly 0.1 mm.	Although less convenient than the aneroid type, the Hg barometer is used for precise measurements and for calibration of other instruments.
Fig. 18—McLeod gage (Flosdorf modification, F. J. Stokes Corp.). Gas at low absolute pressure is trapped in measuring tube by mercury as instrument rotates about a pivot through 90° from horizontal. Mercury compresses gas into top of measuring tube where final volume, expressed as initial absolute pressure, is read.	0.01 to 50 mm. 0.01 to 5,000 micron.	±1%.	Used as primary standard for absolute pressures in micron (0.001 mm.) range. Requires trapping of condensables to avoid error. Can be mechanized, though usually manually operated.
Fig. 19—Single-bellows absolute pressure gage (Bristol). Single evacuated bellows within vessel containing unknown pressure transmits motion outside through bellows seal. Measurement is differential vs. vacuum, hence absolute pressure.	0 to 200 mm Hg.	High accuracy is claimed.	Can be supplied in spans as low as 0 to 6 mm. Hg for vacuum drying, steam condensers, vacuum stills, antibiotic processing.
Fig. 20—Two-bellows absolute pressure gage. Made with either opposed or beam-balanced bellows, one bellows evacuated, other exposed to pressure measured.	0 to 25 psia.	1% or better.	Considered accurate for pressures down to about 5 mm. Hg. Uses similar to above.

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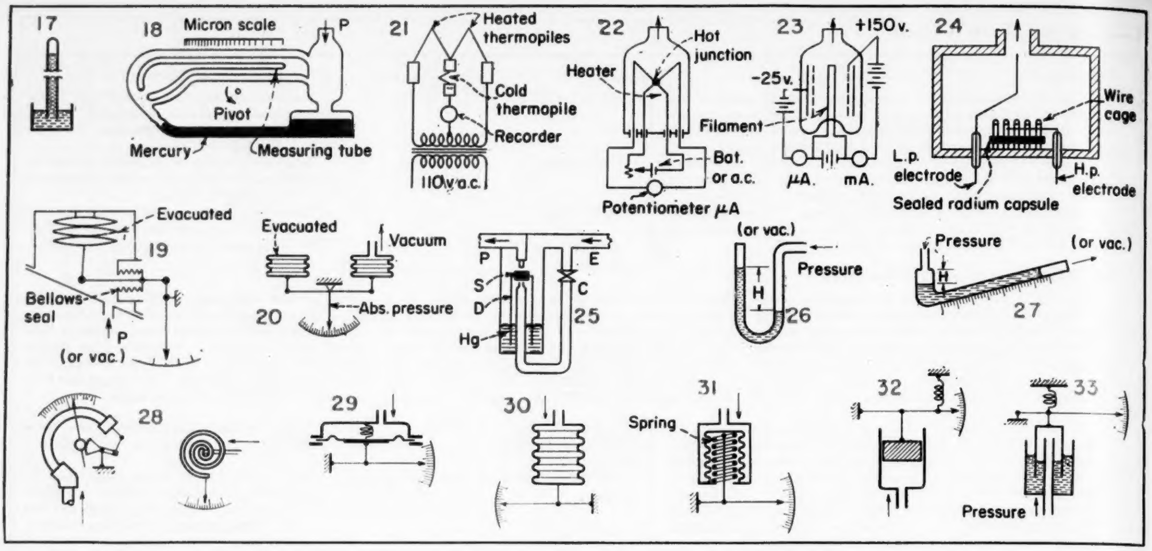

Figs. 17-33—Pressure measuring instruments for absolute and gage pressure and vacuum.

2—Pressure (Absolute, Gage, Vacuum, Draft, Differential) (Cont.)

Principle	*Range*	*Acc'y (p. 288)*	*Applications and Remarks*
(a) Absolute Pressure			
Fig. 21—Noble metal thermocouples are connected in a bridge circuit (Hastings-Raydist, Inc.). Low voltage a.c. supplies current to heated thermopiles. Unheated thermopile connected in opposite polarity provides ambient temperature compensation. D.c. output is measured.	0 to 1,000 micron 0.1 to 20 mm.	High.	Rapid response, not damaged by release to atmospheric pressure. Low operating temperature, no oxidation of thermocouples. Does not measure pressure and so is actually not a manometer.
Fig. 22—Thermocouple gage. Inferential type which measures thermal conductivity of gases at reduced pressure in terms of pressure. Temperature of heater filament is detected by thermocouple.	1 to 200 microns. (Some to 1,000 microns).		Easy to use but must be calibrated on type of gas to be measured. Extends measurement below field of bellows gages and Hg manometers. Fast response.
Pirani gage. Similar in principle to thermocouple gage except that heated filament temperature is measured as a resistance thermometer in wheatstone bridge.	1 to 3,000 microns.		Features similar to thermocouple gage. Uses similar, above range of ionization gages.
Fig. 23—Hot filament ionization gage. Uses three-element vacuum tube containing low pressure gas to be measured. Molecules ionized by electrons from filament flow to plate, discharge, yield plate current proportional to pressure.	0.001 to 1 micron.		Suitable for low absolute pressures but must be protected vs. burn-outs if pressure goes above 1 micron. Unsuited for gases decomposed by hot filament.
Fig. 24—Alpha particle ionization gage (Nat. Research). Similar to hot filament type except that ionization is caused by alpha particles from a radioactive source.	0.1 to 10,000 micron 10 to 1,000 mm.	1%.	Having no filament, there is no burn-out problem, so alpha ionization gage can be used for pressures well above 1 micron.
Fig. 25—Cartesian diver absolute pressure control (Manostat Corp.). Desired absolute pressure is set inside diver D by opening valve C momentarily to system E. Thereafter D closes seat S against nozzle N connecting to pump P unless system pressure changes.	Holds pressures from 1 mm. to 100 psia.	0.1% of set point.	Simple device maintains desired pressure or vacuum. Made in glass or metal. Readily reset to other control pressures.
(b) Gage Pressure or Vacuum (Liquid)			
Fig. 26—Glass liquid columns of U-tube or well type measure pressure, draft or vacuum vs. pressure of atmosphere. Pressure proportional to H.	About 2 in. of liquid head.	About 0.1 in. of manometer liquid	Simple and accurate but limited by glass construction and available column height.
Fig. 27—Inclined draft gage. Similar to U-tube but has one inclined leg vs. large diameter well to increase reading accuracy.		Better than 0.01 in. of liquid.	Used chiefly for low gage drafts and pressures where visual indication is sufficient.
(c) Gage Pressure or Vacuum (Spring Balanced)			
Fig. 28—Bourdon type pressure-deflecting units. Tube of flattened cross-section, as incomplete circle (conventional bourdon), spiral or helix, tends to straighten with pressure increase. Motion is multiplied to pointer by cam or gearing.	0 to 10,000 psia. or higher.	½%.	Most indicating gages use conventional bourdon. Simple, reliable and usually accurate. Cam type (Helicoid Gage) has no back lash, can use suppressed scale.
Fig. 29—Slack diaphragm gage. Slack diaphragm is balanced by pressure or tension of a calibrated spring.	0 to 120 in. w.c.	About 1%.	Used especially for low pressure and draft such as 0 to 0.5 in. w.c.
Fig. 30-31—Bellows type gages. Includes metallic bellows, capsular and multiple-diaphragm units in which pressure is balanced against their own spring action or against a calibrated spring.	Vac. to about 100 psi.	½ to 1%.	Simple and rugged, widely used in moderate-pressure and vacuum instruments, especially in recorders.
Fig. 32—Piston gage. Except for friction, comparable to slack diaphragm. Pressure is balanced by a calibrated spring.	Vac. to high, depending on spring.		Used mainly for study of pressure cycles as in the steam engine indicator. Operates stylus, records.
Fig. 33—Liquid-sealed bell. Inverted bell dips into liquid which acts merely as a seal. Bell is balanced by a calibrated spring.	Vac. to about 15 in. w.c.	1% or better.	Used for low pressures and vacuums; can be made extremely sensitive.
Fig. 34—Force-balance gage seal (Bristol). Process pressure applied to a force-balance pneumatic transmitter, transmitter pressure applied to gage. Restriction in air supply line and leak controlled by diaphragm exactly duplicate pressure.	Any.	1%.	Can be used at gage to protect against corrosive, viscous, dirty or radioactive fluids, or can transmit readings up to 1,000 ft.
Fig. 35—Strain gage load cell (Baldwin-Lima-Hamilton Corp.). Uses small resistance elements bonded to an element which expands under internal pressure. Stretch increases resistance proportional to strain. Usual method assembles four elements in a wheatstone bridge so that resistances A and D are strained, B and C are not. Other resistances are provided for temperature compensation and calibration.	Unlimited.	¼% or better.	Relatively new method becoming popular owing to high accuracy, ease of transmission to millivoltmeter or potentiometer indicator or recorder, good linearity and reproducibility, negligible hysterisis, quick response. Unbonded types also used.

2—Pressure (Absolute, Gage, Vacuum, Draft, Differential) (Cont.)

Principle	*Range*	*Acc'y (p. 288)*	*Applications and Remarks*
Fig. 36—Stainless steel bellows (MSA Research Corp.) senses pressure in liquid metal. The core of the variable transformer is directly connected to the bellows. Variations in pressure are translated into an electrical output which is indicated by a suitable meter or recorder.			Measure pressure of molten metal directly. Pressure range of gage adjusted by linkage in balancing spring. Transformer-windings of transmitter and receiver connected in series, thus providing voltage and temperature compensation.
Fig. 37—Nested diaphragm gage (U. S. Gauge). A variation of the bellows type Fig. 30.	30 in. w.c. to 30 psi.	1%.	Gage withstands high external overpressure without damage.
Fig. 38—Gage protectors. For protection against corrosive conditions, pressure gages are commonly provided with a diaphragm of flexible metal or an elastomer to seal between pressure source and gage. Gage side is solidly filled with liquid such as glycerine. Sometimes a bellows is used.	Vac. to 10,000 psi. or higher.	1%.	Used in corrosive chemical applications with diaphragm metal resistant to use. Also for viscous liquids, or those which might set up in gage. Generally are cleanable.
(d) Gage Pressure (Weight Balance)			
Fig. 39—Deadweight tester. Type of piston gage in which test pressure is balanced against known weight when applied to known piston area. Pressure applied by secondary piston and screw. Weight platform is rotated to avoid sticking.	Unlimited.	0.1%.	Used as primary standard for calibration of gages.
(e) Differential Pressure (Manometers)			
Glass liquid column manometers. Identical with those in Section 2 (b) except that the two pressures are connected, one to each end of the tube.		About 0.01 in. of manometer liquid.	Simple and accurate but limited by glass construction and available column height. Limited static pressure.
Fig. 40—Metal manometers, plain tube. Liquid level, usually mercury, is read by carrying float position outside manometer by pressure-tight bearing, torque tube or magnetic follower.	Differentials of 10 in. w.c. min. to 400 in. or higher.	1%.	Most common method of measurement for rate-of-flow meters. Also for differential-pressure level and density measurements. Static pressures to 5,000 psi.
Fig. 41—Metal manometers, formed tube. Similar to plain tube type except that range tube is formed to variable parabolic cross section to extract square root for flow.		1%.	Not commonly used owing to expense of accurately forming range tube. Gives uniform scale for flow.
Tilting manometer. Manometer balanced on knife edge, and connected by flexible leads to pressure sources, tilts in proportion to differential. By use of cam and counterweight (Cochrane), tilt can be made directly proportional to flow.	About 10 in. w. c. max.	1–2%.	Used for general rate-of-flow measurement. Avoids need for pressure-tight shaft.
Fig. 43—Ring-balance manometer. Similar in principle to tilting manometer. Split tubular ring with flexible leads rotates about central knife edge, balanced by a weight.	About 10 in. w.c. max.	1%.	Used for general rate-of-flow measurement. Avoids need for pressure-tight shaft.
(f) Differential Pressure (Sealed Bells)			
Fig. 42—Floating bell, single. Similar to single-pressure bell (Section 2 c) except enclosed for application of pressure to both sides. Bell position proportional to differential, carried outside by torque tube or pressure-tight bearing.	0.2 to 12 in. w.c.	1%.	Large area of bell gives ample power for operating recording mechanism at very low differentials.
Fig. 44—Formed bell (Bailey Ledoux bell). Bell shaped internally to parabolic form extracts square root of differential to give uniform scale on flow. Hg seal.	212 in. w.c. max. differential.	2% actual flow.	Used for general rate-of-flow metering. Uniform scale facilitates reading and integrating.
(g) Other			
Fig. 45—Slack diaphragm, square-root compensated (Hays Corp.). Addition of calibrating spring in line with motion arm (see sketch) extracts square root for flow.	Min. 0.2 to max. 120 in. w.c. differential.	1 to 2%.	Used for low differential for flow where uniformly divided scale is desired.

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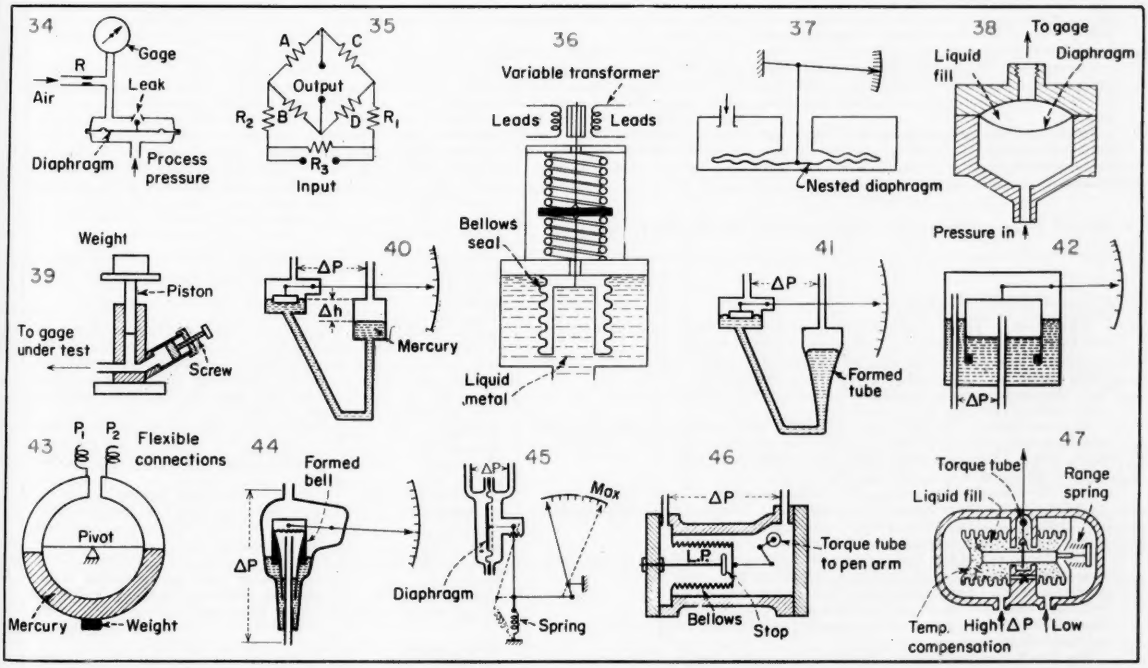


Figs. 34-47—Pressure measuring instruments for absolute and gage pressure, vacuum and differential pressure.

2—Pressure (Absolute, Gage, Vacuum, Draft, Differential) (Cont.)

Principle	*Range*	*Acc'y (p. 288)*	*Applications and Remarks*
Fig. 46—Bellows differential gage, single type. Bellows (or diaphragm) in casing is subjected to low pressure on one side, high on the other. Bellows extension measures differential. Usually provided with calibrating spring for ranging.	Min. 25 to max. 800 in. w.c. differential.	About 2%.	Simple, rugged, range easily changed, requires no mercury, minimizes maintenance. General differential pressure use.
Fig. 47—Double-bellows differential gage (Barton Inst. Corp.). Opposed bellows in two-part casing are filled with liquid, balanced by a spring and connected together by a shaft passing through a restriction. Arrangement acts like spring-balanced piston with high pressure at one end, low at other. Pulsations damped by valve controlling liquid flow from one bellows to other. Temperature compensation for liquid expansion provided by floating bellows section.	Min. 15 to max. 300 in. w.c. differential.	0.5% of full differential.	Unharmed by over-ranging. Range easily adjusted. No mercury. Eliminates pulsation. Torque tube for transmitting motion eliminates possible leakage.

3 — Force, Tension, Compression

Principle	*Range*	*Acc'y (p. 288)*	*Applications and Remarks*
Fluid pressure-spring systems. Most pressure measuring systems in Section 2 can be used for force measurement. Particularly these include spring-balanced devices of Section 2(c). Bellows, diaphragms and capsular elements are commonly used, consisting of two expansible elements coupled by tubing, with the system liquid-filled. Force on one element is transmitted to the other and indicated there as a deflection. Transmitter is usually a stiff spring unit, receiver a bourdon type.	Unlimited	1% or better	Units require calibration but can be rugged and dependable. Indication can be transmitted over several hundred feet.
Pneumatic force balance. Force-balance systems as in Section 25(b) or Fig. 34 balance a force (or a pressure) on one side of a diaphragm against pneumatic pressure on the other, transmitting latter pressure to a pressure indicator.	Moderate force magnitude.	0.5% or better.	Useful where a null system with virtually no displacement of the measuring diaphragm is desired. Can transmit reasonably long distances.
Fig. 35—Bonded strain gages. (See Section 2c) Same strain gage units used for measuring elongation (strain) of pressure-sensitive element can be used to measure strains produced by tension, compression, weight, etc. Four resistance elements in a bridge circuit, or two (one a dummy for temperature compensation) are bonded to strained surface and resistance change measured.	Unlimited.	Strains as small as 0.000001 in. can be measured.	Strain gages mounted on paper, fabric or plastic can be bonded to strained surface by cement, or load measuring units incorporating already-bonded gages are available for measuring weight, force, deflection, motor load, etc.
Unbonded strain gages. Unit consists of two rigid frames laced with four calibrated resistance elements in bridge circuit. Strain tending to pull frame members apart increases strain in one pair, reduces strain in second pair of elements.	Forces to about 4 lb. for displacements to about 0.002 in.		Less used than bonded type. Affords easy method of measuring small strains from ½ oz. to 4 lb., or for building into instruments. Temperature compensated.

4 — Radioactivity Measurements (Applications, see Sections 6 to 9)

General

Geiger-Mueller counter. Metal cylinder with central grounded electrode, is filled with inert gas such as argon. Window of aluminum alloy or suitable non-metal admits radioactive particles or rays. With electrode charged to 1,000–1,200 v. each particle entering causes ionization, momentary conduction, which is amplified and fed to pulse counting electronic circuit. Counting can be speeded with lower pulse strength by lower voltage—then called proportional counter. Detects alpha, beta or gamma radiation. Used in monitors, X-ray diffraction, level and thickness gages.

Ionization chamber. Similar to Geiger but uses low voltage giving minute current proportional to total radiation received. Used in health monitoring, thickness gages.

Scintillation counter. Radiation (alpha, beta, gamma and X-rays, and neutrons) strike phosphor such as zinc sulphide, give off light flashes detected and amplified by photomultiplier tube. Output amplified, fed to pulse counter. Used for general radiation detection and measurement in nuclear laboratories.

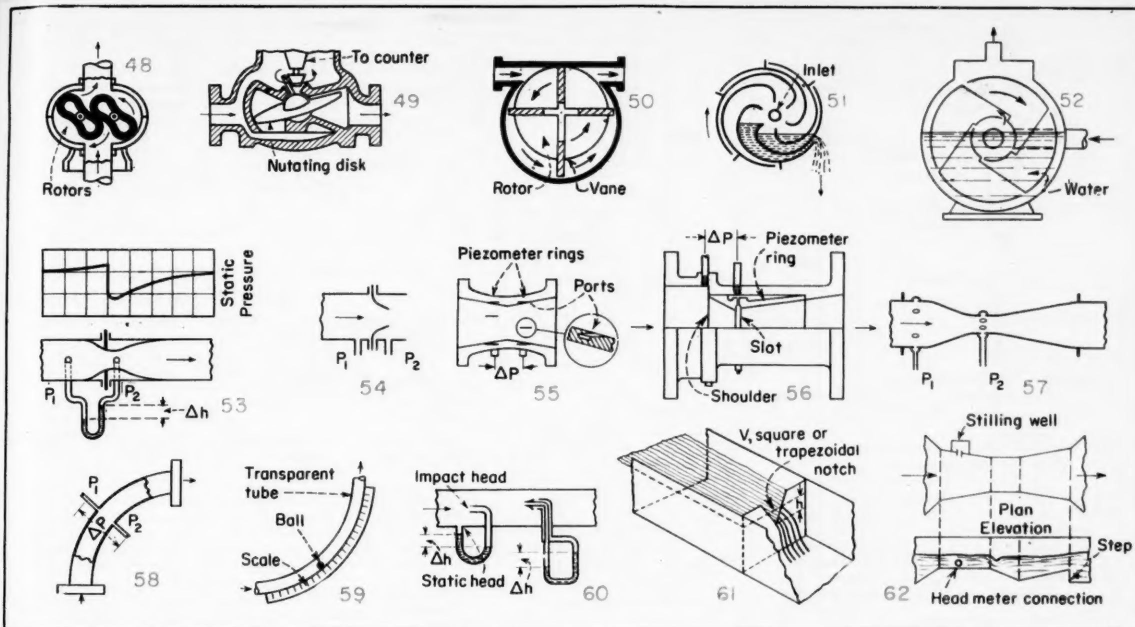
Neutron flux detectors. There are three main types: (1) Boron trifluoride proportional counter is high-voltage ionization chamber with tungsten electrode and BF_3 gas inside. Each boron disintegration due to a neutron causes a pulse at collecting electrode. (2) Fission chamber has electrodes coated with enriched uranium oxide. Each neutron capture causing U-235 fission gives off heavy particles, ionizes gas. (3) Boron-lined ionization chamber can by negative d.c. bias on chamber and a.c. operating voltage compensate for gamma radiation.

Atomic battery (Ohmart Corp.). Generates current direct from gamma radiation, requiring only one vacuum tube for amplification, no high voltage source. Accuracy 2 to 3%. Used for dosimeters, monitors, level gages.

Scalers and pulse counters. Electronic amplifying and registering devices employing trigger circuits to record on lights or mechanical counters, scaling down actual counts by factor of 2 or 10. Integrates pulses over a period of time. Also pulse rate meters, used primarily for graphic recording, or printed digital record (Streeter-Amet).

5 — Fluid Flow (Quantity, Rate and Mass Meters)

Principle	*Range*	*Acc'y (p. 288)*	*Applications and Remarks*
(a) Volumetric Meters			
Piston meter. Piston driven by fluid pressure shuttles back and forth, recording number of strokes in terms of volume passing. Variations include multiple pistons driving wobble plate, double piston in two-part cylinder, reciprocating bellows type used for gas. Piston motion operates poppet or surface-type valves.	Up to 1,500 gpm.	1% or better depending on type.	Gives volumetric measure of flow. In some types can correct automatically for temperature variations. Generally can handle wide range of viscosities. Most commonly used for liquids (except fuel gas meters).
Metering pumps. Many types of positive displacement pumps can be used for metering of liquids when driven at constant speed. Includes piston-type proportioning pumps, piston-type rayon spinning pumps, gear pumps.	Low to moderate.	High.	Depending on type can be used to provide accurate rate of liquid delivery either in discrete increments or in pulsationless flow.
Fig. 48—Lobed rotor meter. Two lobed impellers in a close-fitting chamber rotate without contact with chamber or each other by action of timing gears. Action similar to a gear pump, liquid or gas carrying around outer ends of chamber.	Up to about 1,000,000 cfh.	Variable, depending on slip.	Used chiefly for gases, but can be used for clean liquids. Have low pressure drop Slip increases at low flow rates; best used at higher rates.
Fig. 49—Nutating disk meter. Circular disk in a spherical chamber bounded by cones is cut by a vertical partition near discharge point. Space above and below disk forms two separated chambers which progress from suction to discharge side as disk nutates under liquid pressure. End of axis rotates, drives counter.	1 to 1,000 gpm.	1% or better.	Commonly used for domestic water metering as well as industrial water metering and totalizing of industrial fluids. Often used for batching with automatic shut-off actuated by meter.
Fig. 50—Rotary vane meter. Eccentric drum carries radial vanes forced outward by springs against meter casing to form sealed pockets. Fluid pressure rotates drum.	Moderate.	½% or better.	Can be used for liquids or gases. Has virtually no clearance except at ends so slip is slight.



Figs. 48-62—Flow measuring devices including volumetric and rate-of-flow meters.

5—Fluid Flow (Quantity and Rate Meters) (Cont.)

Principle	*Range*	*Acc'y (p. 288)*	*Applications and Remarks*
Fig. 51—Rotating bucket meter. Curved vanes closed at ends to form buckets are rotated proportional to flow as incoming liquid overbalances drum at right.		High.	Used mainly to measure condensate flow. Is suitable for other liquids.
Fig. 52—Liquid-sealed gas meter. Cylindrical casing more than half full of water contains drum with four "spiral" vanes and gas inlet at center. Gas enters upper compartments, forcing rotation.	Wide range from few cfm. to large size.	0.5% or better.	Used for metering fuel gas and for calibrating other meters. Pressure drop as low as 0.1 in. w.c.

Variable Head Meters — (b) Closed Channel

General: Variable-head meters produce a differential pressure in the case of closed-channel meters, or an elevation of level behind an obstruction in case of open-channel meters. Results in the first type are therefore measured by various forms of differential pressure measuring device (see Section 2 efg) and in the second by level measuring devices (see Section 6). In neither case does flow vary directly with the quantity measured, so that correcting means are often applied to give linear flow scales, e.g., Figs. 41, 44, 45 and 222.

Meters tabulated in this section are rate-of-flow meters. For totalized flow over a period of time they can be provided with integrators or their charts can be planimetered. In meters without linear flow-scale correction the integrator supplies the correction by means of a cam, adding units to a counter at equal time intervals in proportion to the existing flow rate. A simple method of electrical integration is used in the resistance manometer (Republic Flow Meters Co.) shown in Fig. 222. Height of the mercury determines number of resistance elements in series with the manometer output. Elements are arranged so that current output is directly proportional to flow rate. Hence an electrical power integrator similar to a watt-hour meter can be used to integrate the flow.

Meters for compressible fluids are sometimes automatically corrected for static pressure variations, or a static pressure pen records simultaneously on the same chart.

Fig. 53—Orifices. A constriction in a pipe line flowing full gives a reproducible and in some cases predictable pressure drop across the constriction for various rates of flow. Commonest type is the square-edged orifice in thin plate. Such orifices are usually concentric, but may be segmental or eccentric. Pressure connections can be made close to the orifice but are usually at a point well upstream and at point of maximum contraction for maximum differential and accurate predictability. Practically all differential measuring devices in Section 2 efg are used.		High but variable.	Orifice characteristics are well known and predictable. Orifices are relatively cheap but have rather high permanent pressure loss. Accuracy depends on care in construction and installation.
Fig. 54—Flow nozzle, venturi nozzle. First (see sketch) is a streamlined orifice, the second a venturi tube (see below) designed for installation inside pipe. As restrictions, they produce a pressure drop varying with flow rate.	Moderate sizes.	Good.	More expensive than plate orifices, but have lower permanent pressure loss.
Fig. 55—Flow tube (Gentile, Foster Eng. Co.). Streamlined restriction tube flanged for installation in pipe line has ports almost parallel to pipe opening in both up- and downstream slopes to piezometer ring pressure connections.	All commercial sizes.	High.	Gives negligible permanent pressure loss. Shorter and easier to install than most venturi-type differential producers. Turbulence has little effect.
Fig. 56—Flow tube (Dall, B-I-F Ind.). Streamlined restriction tube with abrupt decrease followed by further conical restriction and rapid recovery section. Annular gap averages pressure at throat for solids-free liquids; special design for suspended solids.	31,000 gpm.	±1%	Used for gas, air, water, process fluids, sewage, wastes. Claimed to give lowest permanent loss of any differential producer.
Fig. 57—Venturi tube. Streamlined differential producer with practically unity flow coef., has 20° entrance cone and 5–6° discharge cone for maximum pressure recovery. Pressure openings connect to piezometer rings at throat, entrance.	2 in. and up.	1%.	Used mainly for large flow of water, process fluids, wastes, gases. Gives second smallest permanent pressure loss of any differential producer.
Fig. 58—Elbow-tap flow meter (Foxboro). Centrifugal force of liquid or gas flowing through elbow creates differential pressure between inside and outside of elbow; can be related to flow.			Requires no restrictions; flow can be in either direction.
Fig. 59—Ball-and-quadrant flow meter. Ball in transparent plastic tube bent to quadrant can be calibrated for low flow rates. Constant orifice; variable head supports ball.			Do-it-yourself flow meter for small lab and pilot flows.

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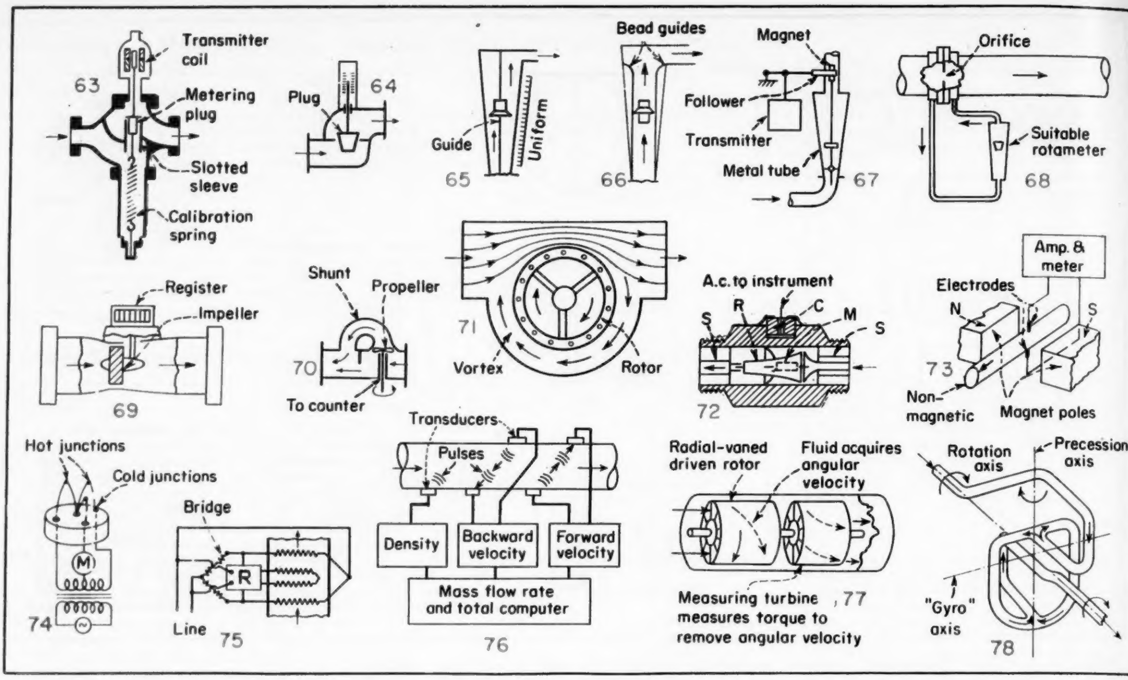


Figs. 63-78—Flow measuring devices including rate-of-flow and mass meters.

5—Fluid Flow (Quantity and Rate Meters) (Cont.)

Principle	*Range*	*Acc'y (p. 288)*	*Applications and Remarks*
Fig. 60—Pitot tube. Measures difference between impact and static pressures in fluid flowing in closed duct, which is proportional to velocity head, $V^2/2g$. Hence gives fluid velocity at a point. With velocity traverse, flow rate can be approximated by using average velocity across duct. Must be calibrated.	Unlimited flow range.	Variable.	Simple device, easily installed and capable of use in very large ducts. Since its flow coefficient cannot be predicted accurately, it must be calibrated.
Variable Head Meters — (c) Open Channel			
Fig. 61—Weirs. Any obstruction in an open channel causes a backing up of flowing liquid which varies with flow rate and can be calibrated in terms of head vs. flow rate. Several predictable forms of obstruction (weirs) have been developed including the V, square and trapezoidal notch which are cut from plate metal according to proportions to give predictable formulas.	Very large.	Fair. Best results need calibration.	Used mainly for measuring large flows of water, sewage or wastes. Usually constructed on the job.
Fig. 62—Flumes. Flow channels with gradual rather than sharp restrictions as in weirs are called flumes. Flow rate varies with head of quiet water behind the restriction, compared with bottom height at restriction. Type shown is Parshall flume. Discharge determined from empirical formula.	Larger than weirs.	Variable.	Used mainly for measuring large flows of water, sewage or wastes, constructed from published dimensions on the job. (See Parshall, Trans. ASCE, 1926).
(d) Variable Area Meters			
In variable head meters the restriction remains constant and the pressure differential is allowed to vary as flow rate varies. In variable area meters the differential is maintained constant and the flow area at the point of restriction is allowed to vary in proportion to the flow rate. Several methods are used, some of which are affected by variations in viscosity. The commonest type is the rotameter, which can be designed to be relatively viscosity-immune.			
Fig. 63—Plug in ported cylinder (Bailey Meter Co.). Cylindrical plug loaded by a weight or calibrated spring moves in sleeve containing rectangular slots. Lift is directly proportional to flow rate. Similar idea (Brown) uses rectangular orifice, makes plug lift directly proportional to flow.	1 to 4 in. ips.	Sensitivity ¼%.	Used for oils and clear liquids, especially for liquids of relatively high viscosity.
Fig. 64—Tapered plug in orifice. With flow against the smaller diameter of the plug, plug rises until upward force due to fluid balances downward force of gravity. Brooks uses this type in a high-pressure indicator with magnetic follower.	Moderate.		Sensitive to changes in viscosity.
Plug flow indicator. Gems Co. makes a flow indicator similar to a lift-plug check valve in which flow against plug bottom lifts plug, actuates magnetically operated switch.	½ to 3 in.	Flow over 1.5 gpm.	Does not meter; indicates flow or lack of it. Switch operates warning light.
Tapered tube rotameter, free bob. This is the earliest type of rotameter, using a top-shaped bob with sloped flutes in the bob to induce rotation with aim of centering bob in tube. Tube is of glass, tapered uniformly and used in vertical position. Upward flow causes bob to seek equilibrium level proportional to flow, where pressure drop equals gravity pull.	½ to 4 in. diam.	½ to 2%.	This type now often superceded in favor of types with guided bobs, and bobs insensitive to viscosity.
Fig. 65—Tapered tube rotameter, center guide. Common type where position of bob is to be indicated on an external scale by direct movement of pointer or by electrical transmission. Inductance bridge (Section 25 c) often used for transmission. Can readily be equipped with electronic, induction or mercury-switch alarm.	½ to 4 in. diam.	½ to 2%.	Used where visual reading of float level is impractical (opaque liquids) or where transmission is required. Permits use of viscosity-immune bobs.

5—Fluid Flow (Quantity and Rate and Mass Meters) (Cont.)

Principle	*Range*	*Acc'y (p. 288)*	*Applications and Remarks*
Fig. 66—Tapered tube rotameter, beaded tube. Commonly used for visual-reading rotameters. Tapered glass tube contains three internal beads of constant internal diameter which guide the bob, taper between beads serving as variable area section.	4 in. max.	½ to 2%.	Used for stability of bobs in visual-read meters. Enables viscosity-immune bobs to be used without center guide.
Fig. 67—Metal tapered tube rotameter (Fischer & Porter Co.). Use of magnetic follower and pneumatic or electric transmitter (see Section 25 b) enables short metal tapered tube to be used.		High	Can handle high pressure as well as high temperature fluids at high accuracy.
Fig. 68—Kinetic manometer rotameter (Fischer & Porter). Orifice or other differential producer is bypassed with a rotameter to give about half the pressure drop through each. Rotameter flow is proportional to main-line flow.			Enables a rotameter to be used for larger than normal flows.
(e) Velocity and Current Meters			
Cup anemometer. Hollow hemispheres mounted radically to form a wheel make a simple sort of current meter. Air current catches open side of cups, producing a rotation speed proportional to air velocity.			Used mainly for wind velocity rather than flow rate.
Vane type velocity meter (Illinois Testing Laboratories.). Impact of moving air or gas against a vane moves it against a hair spring. Used in open air, or with special jet tubes in ducts or restricted locations.	20 to 24,000 fpm.	3%	Used mainly in heating, ventilating, air conditioning and exhaust system design, installation and maintenance.
Fig. 69—Current meters (Builders-Providence). Turbine wheel in a venturi-shaped tube installed in pipe line rotates at rate proportional to flow rate, driving integrating counter.	2 to 36 in. pipe size.	2% of actual flow.	Gives low pressure drop. Used for liquids only. Can stand high temporary overloads. Subtracts reverse flow.
Fig. 70—Shunt type current meter (Builders-Providence). Tube with segmental orifice and bypass loop installed in flow line. Turbine wheel at entrance of shunt measures fixed proportion of main flow, totalizes by magnetic-drive counter.	1 to 14 in. main pipe size.	2% of actual flow.	Used for steam, gas or air only (no liquids). Easy to install, or change orifice for capacity change. Magnetic counter drive eliminates stuffing box.
Fig. 71—Vortex meter (Rotron Controls). Cylindrical flow path with semi-cylindrical bulge in side produces a swirling vortex. Light "vortex cage" set as shown rotates at velocity proportional to flow rate to operate counter.	2 to 220 gpm.	½%.	Virtually no mechanical friction so can be used for non-lubricating as well as lubricating liquids.
Fig. 72—Electric current meter (Potter Aeronautical Corp.). Turbine wheel R mounted between straightening vanes S in cylindrical passage has core shaped to give venturi-like flow, causing end-thrust balance to reduce friction. Rotor R contains magnet M. Rotating field generates a.c. in coil C for flow rate indication. Indication may be combined with density correction for mass flow (Section 5f).	⅛ to 12 in. pipe size	±½%.	Elimination of end thrust said to give high accuracy. Meter has little pressure drop, good for high static pressures to 20,000 psi., temps, to 1,200 F., flow rates 0.1 to 12,000 gpm.
Fig. 73—Induced-voltage electromagnetic flow meter (Several). Liquid flowing through a non-magnetic tube with an internal non-conducting coating in a magnetic field induces a voltage in fluid that is proportional to flow rate and field intensity. Electrodes sealed in tube conduct output to amplifier and flow-rate meter. MSA Research uses this type for liquid metals to 1,500 F.	To 10 in.	½ to 1%.	No pressure drop except straight line loss. Accuracy unaffected by pressure, viscosity, density or character of flow. Response linear with flow rate. Liquid must be slightly conducting.
Fig. 74—Hot wire anemometer. Various types; type of Fig. 74 (Hastings-Raydist) uses thermopile heated by a.c. Cooling by flow, which is proportional to local flow velocity is measured as d.c. output of thermopile by millivoltmeter.	0 to 6,000 fpm. air speed.	2-5%.	Used mainly as a directional or non-directional air velocity meter but can be enclosed (Section 2g) for use as a flow meter.

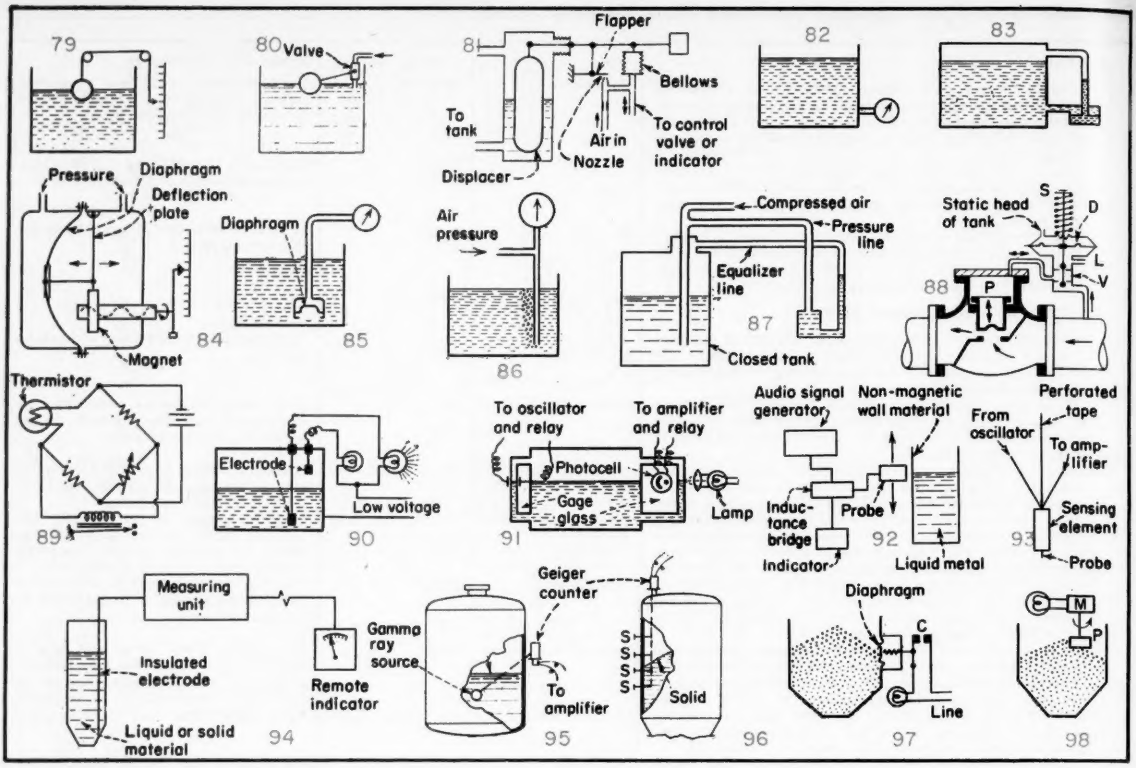
(f) Mass Meters

General: Mass meters measure mass flow rate rather than velocity or volume flow rate. If discrete increments are weighed by an automatic scale-balanced tank which cuts off at set point, then discharges and registers weight, this is a semi-continuous form of mass flow metering. It can be used for batching and for mass flow totalizing. It needs no temperature correction.

Many types of volumetric, differential pressure and velocity flow meters can be modified to incorporate a density correction automatically and so indicate mass flow rate. This has been done with piston meters, head meters especially for gases, but also for liquids, and velocity meters i.e., Fig. 76, the Potter meter (Fig. 72) and electromagnetic meters (Fig. 73).

True mass flow meters, which measure mass directly without a density correction, are in general of two main types: (1) those in which heat or a substance whose concentration can be detected is added to the flow (e.g., dyes, salts or radioactive tracers); and meters which impart angular momentum to the flowing fluid and measure the torque required to do this.

Fig. 75—Heat-addition flow meter. If known heat is added to unknown flow of fluid of known specific heat, temperature rise is inversely proportional to mass flow rate. Type shown (Cutler-Hammer) varies electric current flow to heater for fixed temperature rise, using resistance thermometers in bridge to regulate heat addition. Current flow proportional to fluid flow.	Theoretically unlimited.		Used in gas metering for large flows. Another type has been used for liquid metering.
Fig. 76—Ultrasonic flow meter (W. L. Maxson, others). Consists of a cylindrical flow tube across which are two opposed, diagonal acoustic paths. Each path includes a crystal sender at one end and a crystal receiver at the other. Ultrasonic energy is dispatched along each path in pulses, receipt of a pulse triggering a new pulse. Time of pulse transit is measured in terms of repetition frequency. Time difference for up- and downstream pulses is proportional to fluid velocity, independent of acoustic velocity. A fifth crystal is used to measure density. Energy to produce pulses, proportional to density, is entered into computer with flow velocity to give mass flow rate and total.	Up to 5,000 gpm. (Gulton)	2%	Useful over wide range of temperature and pressure. No restriction in flow tube. Can handle all types of liquids except those containing particles or bubbles comparable in size to acoustic wave length. Maxson type is handled by Fischer & Porter for industrial use.
Fig. 77—Angular momentum meter (G. E., Inertial Instruments, others). Meters of this type have a cylindrical body containing two radially-vaned rotors. The first is rotated at constant speed to impart angular acceleration to the fluid. The second is restrained by a spring or electronically, measuring the torque required to remove the angular momentum put in by the first rotor. Torque is proportional to mass flow rate.	1 to 15 lb./sec.	1% of point at 5 to 1 flow range.	One type (Inertial Instruments) can be used on fluids from 0.2 to 1.5 specific gravity, 0.1 to 25 centipoises, temperatures from −67 F. to 250 F. Weighs only 6 lb. Made in types for liquids or gases, also with either analog or digital output.
Fig. 78—Gyro mass meter (Norwood Controls). Liquid flows through a tube about an axis marked "gyro" while the tube is rotated about the rotation axis. Deceleration taking place as liquid moves toward rotation axis results in precession motion like a gyroscope, tending to cause rotation about precession axis. Tendency is detected in flexible connections, torque to restrain is reported as mass flow. Divided portion of flow path compensates for density changes.	10 to 200 and 25 to 500 gpm.	1% of full scale.	Used for process control, automatic batching and the like. Accuracy is independent of ambient changes in temperature, pressure, viscosity or volumetric flow rate.



Figs. 79-98—Instruments and devices for measuring level of liquids and solids.

6 — Liquid Level

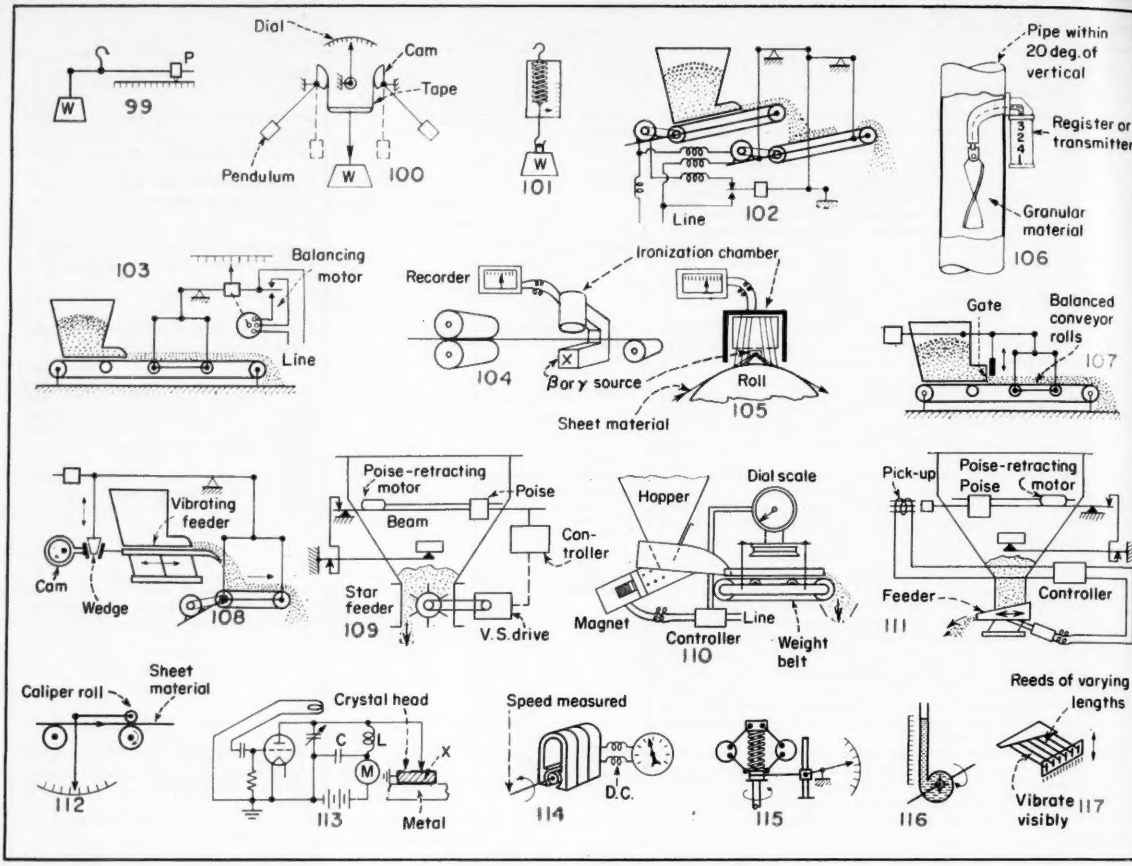
Principle	*Range*	*Acc'y (p. 288)*	*Applications and Remarks*
(a) Float Methods			
Gage glasses. Common level method for visual observation, showing actual level. Many special types for high pressures, low temperature conditions, etc.	Limited only by tank height.	About 0.02 in.	Where applicable this is the simplest and most direct method for level measurement.
Fig. 79—Tank float and external indicator. Many types used with level changes reproduced same size, magnified, or reduced compared with actual changes. Properly weighted, floats can indicate interface level between immiscible liquids.	Limited only by tank height.	About 0.02 in.	Commonest method of indirect level indication; simple, reliable; introduces problems in pressure tanks, but can be handled with various transmissions, e.g., Fig. 214. Fischer & Porter makes float gage with nagnetic follower Gems Co. makes level alarm on same principle.
Fig. 80—Float controlled valve. With or without intervening pilot, float can open or close inlet or outlet valve.	Unlimited.	Variable.	Commonest method of level control.
Fig. 81—Buoyancy displacers. Buoyancy of displacer held at substantially fixed position varies with liquid depth. Pneumatic balance (See Section 25b) can be used to indicate buoyant force in terms of level and operate control valve. More common take motion out via a torque tube to transmitter.	Height of displacer.	High.	System now being used extensively where high-precision control is needed, perhaps 85% of control installations.
(b) Hydrostatic Pressure Methods			
Fig. 82—Direct hydrostatic, gage on tank. Knowing density of liquid, its height above a pressure gage on tank can be inferred directly from gage reading.	Limited only by tank height.	1%.	Limited to tanks not under pressure.
Fig. 83—Direct hydrostatic, differential gage. Use of differential gage such as a manometer compensates for pressure over liquid. Differential directly proportional to hydrostatic head of liquid.	Limited by available manometer differentials.	About 1%.	Suitable for tanks under pressure. With transmitting manometers, level indication can be transmitted long distances.
Fig. 84—Slack diaphragm (Yarnall-Waring Co.). Differential pressure manometer has magnetic transmission converting motion of diaphragm to rotary motion of indicator.	0–3,000 psi. static 6–360 in. w.g. diff.	±2% or better.	Used for level measurement in boilers, heaters, process vessels under pressure. Also for other differential pressure purposes such as flow measurement.
Fig. 85—Bell and diaphragm. Air trapped in closed system of gage, tube, bell and slack diaphragm measures hydrostatic pressure directly.	Limited only by tank height.	About 1%.	Suitable for tanks not under pressure where direct gage connection to tank is undesirable.
Fig. 86—Air bubbler system. Similar to bell and diaphragm except that air flow is maintained through dip pipe, rather than to use trapped air.	Limited only by tank height.	About 1%.	Widely used with practically all kinds of liquids, including corrosives. Requires about 3 cfh. air.
Fig. 87—Differential-pressure bubbler system. Used instead of Fig. 86 where tank is under pressure. Back pressure in dip pipe is piped to one side of manometer, tank pressure to other.	Limited only by tank height.	About 1%.	Uses similar to Fig. 86.
Fig. 88—Altitude valves (Golden-Anderson). Controls main valve through water-pressure pilot to admit water to elevated tank. Head in tank is balanced by spring S on diaphragm D. Head increase lowers pilot valve V, closes leak L, applies main line pressure to top of piston P. Since area of P exposed above is larger than below, main valve closes. If head decreases L opens, V closes and P opens.	2 to 36 in. pipe size.	Controls within 3 to 12 in.	Used to hold constant heads in elevated tanks.

6—Liquid Level (Cont.)

Principle	*Range*	*Acc'y (p. 288)*	*Applications and Remarks*
(c) Other Methods			
Weighing vessel. In a scale-balanced vessel, height of liquid is proportional to weight. Variation of this is to weigh or spring-balance a small auxiliary vessel attached top and bottom to main vessel through flexible leads.	Limited by practical considerations.	High.	Where practical this is the most accurate method readily available. Auxiliary tank method has been used on pressure vessels.
Fig. 89—Temperature-change detector (Gulton Industries). Self-heated thermistor in a bridge circuit changes its resistance when surrounding medium changes from air to liquid, unbalancing bridge and operating relay to control filling system.	Most liquids.	±0.1 in. in any depth.	Simple system for level detecting, or control of filling or emptying.
Fig. 90—Liquid conduction. Probes installed at desired high and low levels. By conduction of electricity probe circuits operate valves, pumps or signals. Can be used with electronic amplification for low-conductivity liquids, e.g., units of B/W Controller Corp., others.	Liquids must have some conduction.	High	Used for high-low control for signalling. Cannot indicate intermediate levels.
Fig. 91—Gage glass automatic detection. Level in gage glass at control point can be detected by condenser plates in an oscillator circuit, or by reduction of light received by a photocell.	Limited only by gage glass.	High.	Suitable for control or signalling in tanks equipped with a gage glass.
Capacitance probe (Fielden Inst. Div.). Glass-covered probe for high, or high and low levels, detects level or interface level by capacitance changes, using oscillator electronic circuit. Conducting liquid unnecessary. This type not for continuous levels. See Fig. 94.	Unlimited.	To 1/32 in.	Can distinguish between liquid and foam. Glass coating makes probe proof against corrosion. Available for both electric and pneumatic control.
Fig. 92—Eddy current liquid metal gage (Nuclear Development Corp. of America). Audio signal generator is used as a source for a balanced inductance bridge. Inductance of one arm of bridge, located in probe, changes due to proximity of liquid metal whose level is measured, due to eddy currents induced therein. Bridge is nulled opposite metal. When it reaches air-metal interface, bridge is unbalanced.	Liquid metal in nonmagnetic containers.	⅛ to 1/16 in.	Expected to be used with liquid-metal heat-transfer media in nuclear field.
Fig. 93—Electronic level gage (Gilbert & Barker Mfg. Co.). Level-sensing device is a small radio antenna in an open-end cylinder. Minute r.f. signals radiated by antenna are affected by submersion. More submersion weakens signal. Return signal sent up same cable retains same strength. Electronic unit compares up and down signals, moves sensing unit (as a surface follower) by means of servo motor to hold signal ratio constant. Tape supporting sensing unit then reports level by measuring hoisting drum position, telemetering to remote indicator.	Unlimited.	±1/16 in.	No possibility of float sticking. Can telemeter long distances. Also telemeters temperature readings at the same time.
Fig. 94—Continuous capacitance gage (Fielden Inst. Div., others). Insulated metal electrode is one side of a capacitor, other side being tank wall. Variations in dielectric character of material between electrode and vessel wall as air-material interface moves are measured on a capacitance bridge as level.	Up to 200 ft. depth.		Can be used also for solids depth. Electrode can be protected against corrosive materials. Indicators may be at remote panel.
Ultrasonic gage (Gulton Industries, others). Electronically vibrated transducer in vessel bottom sends ultrasonic wave upward. Wave reflected back from surface to transducer is reconverted to an electric impulse. Round trip timed electronically.	Limited only by tank height.	1%.	Particularly useful with corrosive liquids since transducer is outside tank. Second transducer path across fixed distance is used to correct inaccuracies.
Fig. 95—Gamma ray absorption. Gamma ray source in vessel gives off radiations detected by Geiger counter tube outside tank. Geiger output decreases as level rises and can be calibrated in terms of level. For wide range coverage several gamma sources are used at different levels. Geiger output is amplified and converted to d.c. proportional to pulse rate. Atomic battery (Ohmart, Section 4) may be used for detection instead of a Geiger counter.			Can be used where most other level methods might be banned for safety reasons. No opening is needed through vessel. Can be used to control.

7 — Solids Level

Principle	*Range*	*Acc'y (p. 288)*	*Applications and Remarks*
Fig. 96—Gamma ray gage. One or more sources of gamma radiation within solids-containing vessel give off radiation detected by Geiger counter outside vessel. Absorption depends on density and length of path through solids so radiation received is inversely proportional to level (or density). Atomic battery (Ohmart, Section 4) may be used for detection.	About 2 ft of solids level per source, depending on density.		Used in solids bins, fluid and other cat crackers. Requires no opening or connection through vessel wall. Knowing height, can be used to determine density of fluidized beds.
Fig. 97—Flexible diaphragm (Bindicator Co.). Flexible diaphragm in bin wall moves if contacted by solids, thus operating switch. When level falls, spring returns diaphragm and switch to former position.	Unlimited.		One unit can be used to detect high or low level of solids. Two detect high and low, to operate signals or conveyors. Intermediate levels detected similarly.
Fig. 98—Rotating paddle (Fuller Co., others). Paddle P at desired top level is rotated by a motor M mounted so that increased torque operates switch when solids reach paddle.	Unlimited.		Can be used only for top level detection but can operate signal or shut off conveyor.
Pendant cone (Stephens-Adamson Mfg. Co.). Cone with apex upward is suspended from housed switch so that movement in any direction from vertical by solids makes contact.	Unlimited.		Can be used only for top level detection but can operate signal or shut off conveyor.
Balanced paddle (Conoflow Corp.). Paddle on horizontal arm extending into vessel through diaphragm seal is balanced by pneumatic-balance transmitter. Contact with solids unbalances arm, transmits to indicator or controller.	Unlimited.	High.	Designed to measure level of hot catalyst at temperatures to 1,000–1,100 F. Rapid response.
Slack detector (Dracco Corp.). Small weight w on a cable is lowered periodically into bin by a cycle-controlled winch W. When it strikes solids a slack detector D stops and reverses winch, leaving indicator S at corresponding position. Cycle then repeats so that indicated level is corrected each cycle.	Any practical height.	High.	Intended primarily for continuous indication and recording of level in bins but can also be used for control.
Weighing vessel. Knowing vessel diameter, weighing vessel and contents is most accurate method of determining solids level, where practical.	Limited by practical considerations.	High.	Uncommon method limited by expense of weighing large bins. Strain-gage weighing may increase use.
Noise control for grinding mill level (Hardinge Co.). Microphone near a ball, rod or tube mill indicates sound level at which material level in mill is optimum for maximum grinding action. Microphone output amplified, used to control feeder.	Limited only by available mill sizes.	High.	Work being accomplished by mill is directly related to amount of sound produced. Method prevents over- or underloading without operator attention.



Figs. 99-117—Devices for measuring weight, weight rate of flow, thickness and speed.

8—Weight and Weight Rate of Flow

Principle	*Range*	*Acc'y (p. 288)*	*Applications and Remarks*
(a) Fixed Load Weighing			
Fig. 99—Uneven-balanced scale. Simplest form, the steelyard, shown in Fig. 99, illustrates principle of most weight-balanced industrial scales. Unknown weight on a short moment arm is balanced by movable known poise (or known weights plus poise) on a long moment arm. Industrial scales (e.g., Fig. 102) introduce additional levers between unknown weight and beam which increase ratio of unknown to poise.	To 400,000 lb. or more.	About 0.1% of actual weight is possible.	Most widely used weighing method for industrial use. Includes manual and automatic types. Indications on dial available. Some types print weight automatically.
Fig. 100—Pendulum-balanced scale. One or more pendulums balance increasing loads as they move from vertical (zero) to horizontal (maximum). Because load balanced varies as sine of displacement angle, cams are used to give linear scale graduation. Cam may be on pendulum or on pointer. Metal tape transmits motion.	Same as beam scales since lever reduction can be used ahead of pendulum mechanism.	Same as beam scales.	Commonly used in both commercial and industrial scales, especially where dial indication of weight is desired. Available in recording and printing types, also with photoelectric cut-off. Toledo has developed remote digital recording for scale.
Fig. 101—Spring-balanced scale. Spring deflection within limits is directly proportional to load, so deflection can be used as a measure of weight supported.	Generally used for moderate weights.	Can be as high as 0.05%.	Commonly used for small commercial scales, but is also used to balance beam in automatic industrial scales.
Hydraulic (spring) balanced scales. Force produced by load is detected by liquid-filled capsular element, transmitted to spring-loaded pressure-sensitive element.	Used mainly for moderate to large loads.	High.	Used in crane-hook scales and other industrial applications.
Tension-balanced load cell (strain gage) (Baldwin-Lima-Hamilton Corp.). See Sections 3 and 2c, Fig. 35. Strain gages bonded to calibrated tension element measure load in terms of lengthening of element. Resistance change in strain gage is measured by a bridge circuit. Unbonded strain gages may be used for smaller loads.	Up to 50,000 lb. per load cell.	¼% full scale.	Used for both stationary and moving loads. Easily weighs tanks, bins and hoppers. Made also in automatic printing type (Streeter-Amet Co.).
(b) Moving Load Weighing			
Fig. 102—Semi-continuous feed-belt weigher (Richardson Scale Co.). Scale-balanced weigh belt controls operation of a feed belt. Scale belt runs continuously but is fed intermittently with loads shorter than its full length so that a definite increment is weighed. Increments come close together, approximate continuous flow.		High.	Used to record receipt and withdrawal of bulk materials and for batching of solids.
Scale-mounted feed tank (liquids). Feed tank on scale is filled to set point, after which feed valve is closed. Tank discharges automatically, weight is registered and cycle repeats. Variation used for accurate weight rate of feed allows liquid to discharge only as fast as weight setting of scale decreases through action of motor-driven beam poise (Proportioneers Inc.).	Limited only by practical weight tank size.	0.1%.	Used where accuracy of other methods such as volumetric or head-type flow metering, or pump displacement, is insufficient.

8—Weight and Weight Rate of Flow (Cont.)

Principle	*Range*	*Acc'y (p. 288)*	*Applications and Remarks*
Fig. 103—Continuous conveyor scale. Scale-balanced section of belt conveyor used to totalize continuous loads is made in many variations. Various forms of automatic weighers used including spring-balanced beams, strain gage load cells and motor-driven-poise self-balancing scales. Totalizer integrates instantaneous loads with belt speed to take care of possible belt speed variations.	Limited only by conveyor sizes available.	½ to 2% depending on % of rated load.	Commonly used on bulk materials where continuous record is needed for inventory purposes. Such scales give quick response to load variations. Some subtract weight of material sticking to return belt.
Fig. 104—Radioactive transmission gage, absorption type. (See also Section 9 and Fig. 105.) (Industrial Nucleonics Corp., others.) Beta or gamma radiation from a radioactive source passes through moving web of material to an ionization chamber. Attenuation of signal is a measure of the weight of material passing. Recorded as either weight or thickness.	Usual thicknesses of sheet materials.	1-2% or better.	Used for continuous measurement of weight per unit area (or thickness) of moving webs of sheet materials such as paper, rubber, plastics, coated fabrics, metals. Unaffected by water, surface finish, etc.
Fig. 105—Radioactive transmission, back-scattering type. (See also Section 9 and Fig. 104). (General Electric, others.) Variation of absorption type where source and ion chamber are on the same side of material measured, radiation reflected from a backing plate being measured. Measures either weight passing or thickness, depending on calibration.	Usual thicknesses of sheet materials.	1-2% or better.	Used for continuous weighing or thickness measurements on moving webs of sheet materials such as paper, rubber, plastics, coated fabrics, metals. Also for thickness of surface coatings on metal, e.g., tin, plastics.
Fig. 106—Volumetric solids meter (Bailey Meter Co.). Spiral vane suspended in a duct containing moving solid material rotates without slip in proportion to motion. Connected register records revolutions in terms of integrated volume or weight passing. Can transmit to remote integrator.	For spouts 10 in. diam. or larger.	±3% of actual material weight.	Device used on spouts not over 20° from vertical. Being volumetric, it must be calibrated on material handled to permit conversion to weight flow.
(c) Weigh Feeders			
Fig. 107—Scale-balanced belt feeder (Schaffer Poidometer). Scale-balanced feed belt controls setting of feed hopper gate to maintain constant weight on belt.	Moderate range.		Used for feeding solids at constant rate to processes.
Fig. 108—Balanced weigh belt, mechanical feeder (Omega Machine Co.). Short feed belt carried on a scale is fed by a mechanically vibrated tray (smaller than shown, in later models). Oscillation of tray, controlling feed rate, is governed by scale beam through raising or lowering of a resilient wedge.	Feed range adjustable. 100 to 1 range. Up to 10,000 lb./hr.	1% of feed rate.	Used on all types of free-flowing solids for both feeding and proportioning. Variable-speed star feeder may be substituted for vibrator.
Fig. 109—Loss-in-weight feeder (Omega Machine Co.). Scale hopper is discharged by a star feeder driven by a variable-speed drive. Scale beam counterpoise is retracted continuously by a constant-speed motor. Pneumatic controller acts to hold beam in balance by matching discharge rate to feed rate set by retracting poise.	100 to 1 feed range. Up to 40,000 lb./hr.	±½% of feed rate.	Handles dry materials in chemical, fertilizer, plastic and other industries. Can be granular, lumpy, stringy, etc. Poise retraction speed is adjustable.
Fig. 110—Balanced belt, electric vibrating feeder (Syntron Co., other). Weight of material on a short feed belt is controlled continuously by automatically adjusting the vibration amplitude of an electrically vibrated trough feeder.	Wide range.		Suitable for free flowing solids. Adjustable over wide range.
Fig. 111—Loss-in-weight feeder (Syntron Co.). Scale hopper is discharged by an electric vibrating feeder. Scale beam counterpoise is retracted continuously by a constant-speed motor. Electronic pickup and control system adjusts feeder rate to match feed rate set by retracting poise.	3-cu. ft. hopper.	Less than 1% error.	Handles dry chemicals and similar materials. Poise retracting speed is fully adjustable.

9 — Thickness and Displacement

Principle	*Range*	*Acc'y (p. 288)*	*Application and Remarks*
Fig. 112—Caliper roll. Roll riding on moving sheet material above a fixed reference roll shows thickness by distance from reference. Measurements multiplied in various ways such as mechanically, or by strain gage.	Usual thicknesses of sheet materials.	Variable depending on construction.	Suitable for moving webs of sheet materials where physical contact will not be harmful.
Pneumatic jet. Moving sheet material passing over a reference roll can be gaged by backpressure in a jet directed at, and close to, the surface. Can be hooked into a pneumatic force-balance system for amplification and transmission of indication. Jet can also be used for edge tracking (Askania).	Usual thicknesses of sheet materials.	High.	Variations of this system have advantage that physical contact with moving web is not required.
Fig. 113—Ultrasonic resonance gage (Branson Instruments). Ultrasonic wave from a crystal head in contact with tested material passes through material, reflects back to head. When round trip time equals vibration frequency, resonance is attained, causing increase in circuit power. Frequency set by adjusting values of C and L. Point of maximum energy absorption determined from microammeter M.	1/16 to 12 in. metal thickness.	3% or better.	Calibrated from known thickness of material to be measured. Can determine thickness of pipes, vessels, etc., where other surface is not available. Used in checking for corrosion.
Beta and gamma ray absorption and back-scattering. See Section 8b, Figs. 104, 105. Same principle is used for measuring thickness as for weight. Weight actually measured, but can be calibrated in thickness if density is constant. Similar principle used in detecting corrosion thinning of pipe and tank walls by measuring thickness from one side.	Usual thicknesses of sheet materials.		Used for continuous thickness measurements on web materials such as paper, rubber, plastics, coated fabrics, metals. Unaffected by water, finishes, etc.
X-ray back-scattering (Philips Electronics, Inc.). X-ray beam set at 70° from surface of moving sheet of tin plate produces secondary radiation from steel backing which is back-scattered to Geiger tube. Intensity of secondary radiation is a function of tin plate thickness. Duplicate units on both sides gage both surfaces. Two-beam type (Applied Research Labs.) compares reflected K radiation from tin with scattered radiation from parts of spectrum independent of tin thickness, recording ratio of two types as weight.	Usual tin plate thicknesses.	High.	Used specifically for tin plate.

10 — Velocity (Linear and Angular)

Principle	*Range*	*Acc'y (p. 288)*	*Application and Remarks*
Air-speed indicators. Include such devices as cup and vane anemometers, hot-wire anemometer and pitot tube (Sect. 3).	Various.	Various.	Used in meteorology, flight, air conditioning and ventilation.
Conversion of linear to angular velocity. Speed of moving surfaces such as moving web or surface of drum or roll can be measured by contact with a wheel of known circumference.			Used for measuring output of processes producing web materials.

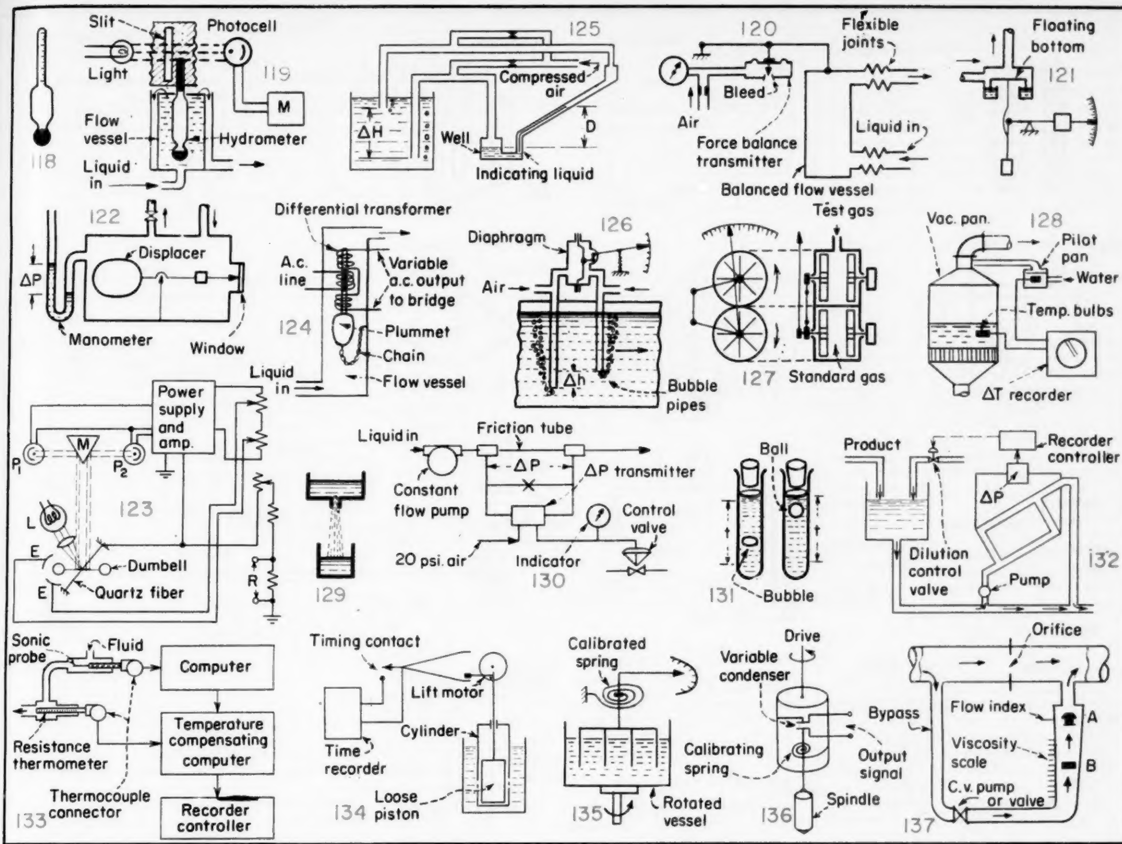
Continued next page

10—Velocity (Linear and Angular) (Cont.)

Principle	Range	Acc'y (p. 288)	Applications and Remarks
Fig. 114—D.c. magneto tachometer. Small permanent magnet generator produces a voltage directly proportional to speed of rotation. Measured by voltmeter.	1 to 5,000 rpm.	Up to about 1%.	Commonest industrial rotational speed device. For speeds beyond its range can easily be geared.
A.c. generator tachometer (General Electric Co.). Single-phase alternator driven at speed to be measured produces frequency directly proportional to speed.	0 to 4,000 rpm.	About 4%.	Needs less maintenance than d.c. tachometers since it has no commutator or brushes.
Magnetic drag tachometer. Type used in automobile speedometers. Rotating magnet induces eddy currents in a surrounding aluminum cup, tending to drag cup with it in proportion to speed.	0 to 2,000 rpm.	Up to 10%.	
Fig. 115—Centrifugal governor. Flyballs, restrained by a spring, compress spring proportional to square of speed.	Top about 40,000 rpm.	1% or better.	Used chiefly for speed regulation rather than measurement.
Fig. 116—Velocity head meters. Small centrifugal pumps and blowers deliver an output to a manometer or gage where velocity head is converted to static pressure.		Can be high.	Not much used industrially. Calibrated in terms of speed of the pump or blower.
Fig. 117—Vibrating reed (Jas. G. Biddle Co.). Meter contains a set of consecutively tuned steel reeds. When a vibrating machine part contacts meter, any reed tuned to resonance with the vibration frequency will respond visually.	600 to 100,000 rpm.	0.5% of actual frequency or better.	Capable of measuring very high vibration frequencies. Needs contact only with a non-moving part of rotating machine.
Stroboscopes. For measurement of rotational speed or other cyclic movement, stroboscopes can be used to "stop the motion". Speed of the stroboscope itself is then measured without need to contact the rotating part. Stroboscopes are of various types, all permitting the moving object to be viewed once per cycle, as with shutter or flashing light.	Unlimited, by use of harmonics.	Synchronization perfect.	Main use in experimental work, trouble shooting.
Tachometer transmitter (Foxboro). Magnetic drag disk torque is transmitted by a pneumatic force-balance system. Output pressure is directly proportional to speed of rotation.	Various from zero to 12,000 rpm.		Developed for industrial systems.

11 — Fluid Density and Specific Gravity

Principle	Range	Acc'y (p. 288)	Applications and Remarks
(a) Weight methods — Hydrometer			
Fig. 118—Hand hydrometer. Weighted float with small diameter stem at top sinks in liquid to depth proportional to specific gravity, scale is read at liquid level.	Adaptable to any specific gravity.	Third or fourth decimal place.	Widely used where automatic operation is not needed.
Fig. 119—Photoelectric hydrometer (Ess Instrument Co.). Glass hydrometer in continuous flow vessel has opaque stem which rises or falls in front of a slit. Illumination on one side of slit passes through, falls on photocell. Stem position determines amount of light passing, hence output of photo.cell	Any specific gravity of liquids.	Second or third decimal place.	Suitable for all specific gravity recording applications not harmful to glass. Various ranges available. Sensitivity depends on range.
(b) Weight methods — Fixed Volume			
Fig. 120—Balanced flow vessel. Fixed volume vessel through which liquid flows continuously is weighed automatically by scale or force-balance transmitter.	Any specific gravity of liquids.	High.	Generally applicable to automatic density control.
Fig. 121—Gas specific gravity balance (Alpha-Lux). Weight of tall gas column is measured against air by floating bottom of gas vessel, which is scale-balanced.	Any density of gases.	High.	Similar to but more convenient than two-pipe system described above. Suitable for any gas. Can be made recording.
Fig. 122—Buoyancy gas balance (Edwards). Displacer on balance beam in vessel is balanced for air and manometer reading noted at exact balance pressure. Air then displaced by gas and pressure adjusted until balance again attained. Ratio of pressures is density relative to air.	Any density of gas.	Fourth decimal place.	Used mainly for high-precision laboratory measurements. Cannot be adapted to continuous measurement.
Industrial specific gravity displacer. Similar to displacer for level measurement (See Section 6a) except that float is submerged and is counterbalanced externally.	Any liquid density.	Second or third decimal place.	Widely used method for industrial recording and control of liquid density.
Fig. 123—Gas density balance (A. O. Beckman). A null-balance instrument. Gas density measured by buoyancy of one ball of dumbbell compared to other ball which is punctured and is not subject to buoyancy effects. Rotation of rhodium-coated dumbbell about horizontal quartz fiber produces electrostatic force between electrodes and the suspension. Balancing potential is obtained and measured by the amount of light received by phototubes P_1 and P_2. Rebalance potential nulls balance, is recorded as gravity relative to air.	0 to 2.000 relative to air.	½%.	Continuous measurement of a process stream. Compensated for barometric changes. Calibrated manually on known reference gas, usually air. Single range has total span of 0.100 units; multi-range is 1.000 units relative to air.
Fig. 124—Chain-balanced-float density recorder (Precision Thermometer & Instrument Co.). Bob in continuous flow vessel is weighted to carry half the weight of a light chain when submerged in median density liquid at midpoint in its range. Chain attached to bottom of float and to vessel wall at half height. Density increase causes float to rise, supporting more chain; decrease, to sink, supporting less chain. Float position transmitted by differential transformer.	Liquid gravity range, 0.6 to 3.5 sp. gr.	High.	Can be used for recording and/or control. Available to resist most corrosive conditions. Suitable for practically any liquid. Note this is a method of actually weighing fixed volume of liquid. Can be corrected for temperature variations.
(c) Other methods			
Fig. 125—Differential air bubbler (Petrometer Corp.). Air at regulated pressure and quantity is bubbled through two dip tubes of different lengths submerged in liquid. Differential pressure is a measure of the weight of liquid column between dip tube ends, hence of specific gravity of the liquid. Head D of indicating liquid is directly proportional to specific gravity of liquid in tank.	Any liquid density.	0.001 sp. gr. units.	Suitable for practically all liquids except those which will crystallize in the measuring pipes. Can be used on suspensions, on stationary or flowing liquids. Can use liquid instead of air.
Fig. 126—Differential air bubbler. Same principle as Fig. 125 except uses diaphragm type manometer.	Any liquid density.	About 0.3 to 1%.	Same as Fig. 125.
Fig. 127—Viscous-drag gas density meter (Ranarex type, Permutit Co.). Driven impellers in standard and test gas chambers produce opposite rotation in gas columns. Non-rotating impellers coupled together by linkage measure relative drag, balance point depending on relative density.	Usual industrial gases.	About 0.01 sp. gr.	Often used for determining compensation of binary gas mixtures—an analysis rather than a density instrument. Calibrated on gases to be measured.
Fig. 128—Boiling point elevation. Compares temperature of boiling solution with that of water boiling at same pressure. For particular solution, boiling point elevation can be calibrated in terms of density at standard temperature.	One dissolved component or mixtures of fixed composition.	High.	Method used in evaporators for determining end-point of evaporation. Commonly uses resistance thermometers to record difference in the two temperatures.



Figs. 118-137—Instruments for measuring liquid and gas density and liquid viscosity.

12 — Viscosity and Consistency

Principle	*Range*	*Acc'y (p. 288)*	*Applications and Remarks*
Fig. 129—Timed discharge through nozzle. Method of viscometers such as the Saybolt. Vessel with short capillary tube has discharge timed at desired temperature.	Low to moderately high.	High.	Commonly used for expressing viscosities of oils.
Fig. 130—Pressure drop through friction tube. Liquid pumped at constant rate through friction tube in viscous flow. Pressure drop across ends of tube is measured by pneumatic force-balance type differential pressure transmitter in terms of absolute viscosity. Gives direct solution to Poiseuille's equation.	Up to 3,000 cp.	0.2 cp. in span of 50 cp.	Can be used for wide range of industrial liquids, for remote recording and control. Extremely simple and foolproof. Requires no attention.
Fig. 131—Timed fall of ball or rise of bubble. Time for fall of metal ball or rise of bubble through liquid confined in tube is proportional to absolute viscosity since in either case liquid flows in viscous flow through a definite restriction.	Used primarily for high viscosities.	High.	Both are laboratory methods commonly used in measuring oil viscosity. Ball method can be timed with great accuracy by field coils at start and finish.
Fig. 132—Continuous consistency meter (Fischer & Porter Co.). Gear pump diverts a portion of product stream through flow bridge where a pressure differential between two reference points is established. The differential pressure is a direct measure of the consistency of the material.			Measures, records and controls the consistency of fibrous or pulpy slurries.
Fig. 133—Ultra-Viscoson continuous viscometer (Bendix Aviation Corp.). Ultrasonic waves are applied to a thin magnetostrictive alloy-steel blade. Rate at which oscillations of the blade are damped is a measure of viscosity of the sample. Relation between damping and viscosity is solved continuously by a computer.	0 to 50,000 (in 4 steps) centipoise-grams/cc.		Ultra-Viscoson can be used in Newtonian liquids, non-Newtonian liquids and on high polymers. Probe can be immersed in any process vessel as well as in laboratory equipment.
Fig. 134—Viscometer (Norcross Corp.). Piston is raised in a timed sequence and falls by gravity through liquid. Clearance between piston and cylinder forms measuring orifice. Time of fall is recorded as a measure of viscosity.	0.1 to 10^6 centipoises.		Covers the same range of materials as Fig. 133.
Fig. 135—Drag torque on stationary element in rotated cup. Some types use a cylinder, others a paddle as shown (Brabender). Liquid cup rotates at constant speed, stationary element is restrained by calibrated spring which, by angular displacement, measures torque in terms of viscosity.	Wide range, Newtonian and non-Newtonian.	High.	Primarily a laboratory instrument but may be equipped to record. Bowl is often surrounded by thermostatic housing for close temperature control.
Fig. 136—Torque to rotate a torque element in a liquid (Brookfield Eng. Co.). Synchronous motor drives vertical spindle with disk, paddle or cylinder submerged in test liquid. Drive is through calibrated spring. Angular lag of spindle behind motor is proportional to viscosity and is measured in various ways. Controller detects angle of displacement by periodic electric contact. Recorders adapted to this device by several instrument makers measure angle three ways: capacity change, resistance change and timed impulse.	0 to 500 poises, with minimum span of 0 to 1 cp.	1 to 2%.	Can be used in open or closed vessels, under pressure or vacuum, at high or low temperatures. Used for both Newtonian and non-Newtonian liquids or suspensions.

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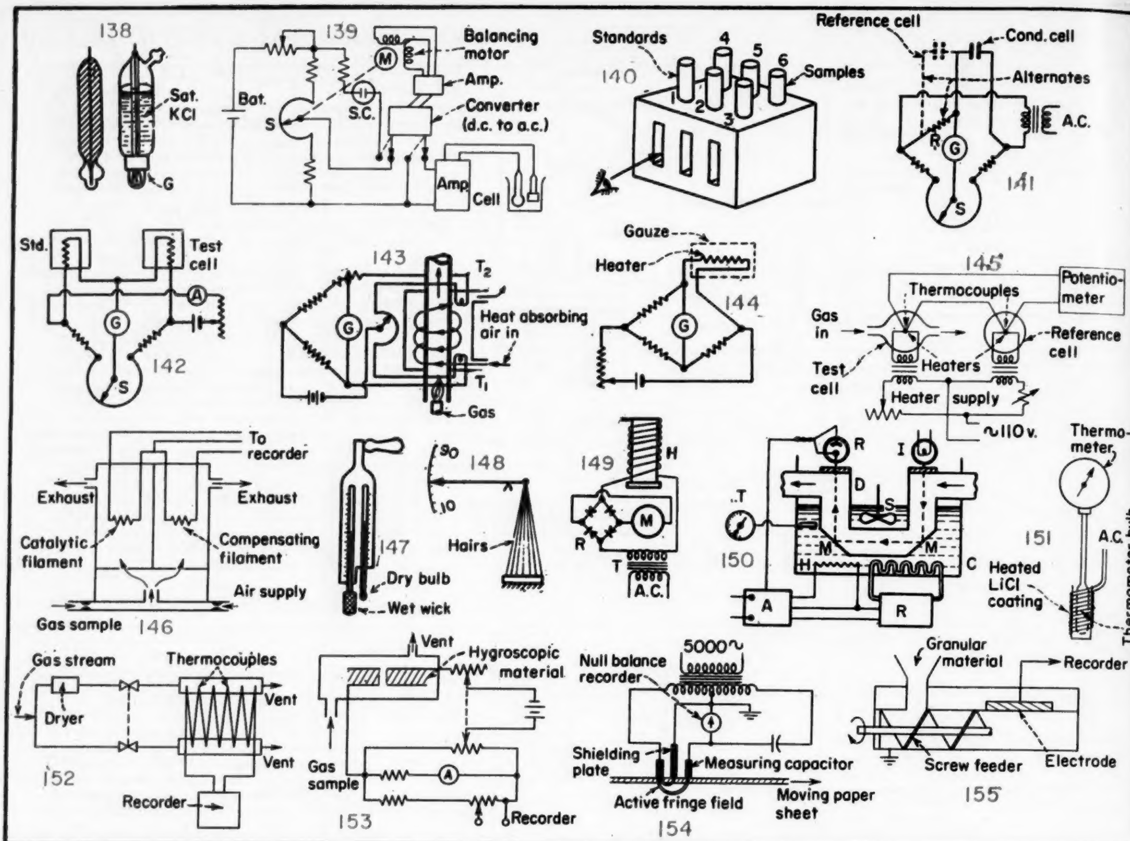


Figs. 138-155—Instruments for pH, thermal and electrical conductivity, calorific value and humidity.

12—Viscosity and Consistency (Cont.)

Principle	*Range*	*Acc'y (p. 288)*	*Applications and Remarks*
Fig. 137—Viscosity-sensitive rotameter (Fischer & Porter Co.). Rotameter bobs can be designed for either sensitivity or immunity to viscosity. With constant flow rate a sensitive bob can be calibrated for viscosity. One method is to use immune bob to set flow rate at index mark.	Up to 400 centistokes; special type to 1,000,000 cp.		Suitable for both Newtonian and non-Newtonian liquids and suspensions in continuous flow. Used for visual and remote readings and control.

13 — pH Concentration, Oxidation — Reduction Potential

(See Fig. 138) pH is measure of effective acidity or alkalinity as concentration of hydrogen ions. Numerical measure is negative logarithm of the concentration. Fundamental method, used in calibration and laboratory work, is hydrogen electrode vs. standard calomel electrode. Both electrodes, in liquid to be measured, at standard temperature, produce potential proportional to H-ion concentration. Result measured with potentiometer.

Other electrodes used include antimony and quinhydrone, not much used now; and glass electrode, now generally used. Fig. 138 shows glass electrode and calomel reference electrode. Glass electrode is thin glass bulb with silver electrode immersed in silver salt solution, now available in types of pH 0 to pH 14. It develops potential proportional to H-ion concentration. Calomel electrode produces fixed potential regardless of pH. Its inner tube contains calomel and mercury, is immersed in outer tube containing saturated KCl. Electrical contact with test solution is through ground joint or capillary leak G.

Principle	*Range*	*Acc'y (p. 288)*	*Application and Remarks*
Fig. 139—Electrometric method. Potential produced by pH electrodes (see above) is measured by sensitive amplifier and self-balancing potentiometer. Circuit shown is that of Bailey Meter Co. using Beckman electrodes. Circuit contains resistance thermometer (not shown) for automatic temperature compensation. Potential of high-resistance glass half-cell vs. standard calomel half-cell is amplified electronically, then balanced vs. fixed voltage in d.c. potentiometer. Potentiometer battery is standardized periodically vs. standard cell SC, by switching SC into circuit instead of pH cell. Potentiometer output, if unbalanced, is converted to a.c., amplified, and applied to potentiometer-balancing motor M which adjusts slide-wire S for re-balance. Position of S determines pen location, calibrated in pH.	Various electrodes cover various ranges from pH 0 to pH 14.	0.02 pH or better.	Used for measurement and control in numerous applications in practically all process industries for controlling reactions, measuring product quality, controlling flocculation and coagulation, controlling waste effluents, etc.
Fig. 140—Colorimetric method. Inferential method of pH measurement based on fact that various indicators will give color changes dependent on pH. Colors then compared with color standards using a visual comparator, principle of which is shown in figure. Tubes 1, 2 and 3 hold color standard, distilled water and next higher color standard. Tubes 4, 5 and 6 hold test material, material plus indicator, and test material. Standards changed in 1 and 3 until matched.	0.2 to 13.6 pH.	0.1 pH.	Used in laboratory and plant work wherever manual pH measurement is desired. Much less costly than electrometric equipment.

13 — pH Concentration, Oxidation—Reduction Potential (Cont.)

Principle	*Range*	*Acc'y (p. 288)*	*Applications and Remarks*
Oxidation-reduction potential (Beckman Instruments, Inc., others). In "redox" reactions negatively charged electrons are transferred between reactants, e.g., ferrous ion losses an electron, becomes ferric (is oxidized or gains increased positive charge). Such a reaction does not necessarily involve presence of oxygen. Reduction is reverse. Inert metal electrode vs. calomel reference electrode (c.f. pH measurement) will develop potential showing balance of oxidized vs. reduced ions in solution. Must be corrected for temperature and pH. Result is Eh.			Can be used to follow progress of redox reactions and control addition of reagents. Equipment same as that for pH except for substitution of gold or platinum electrode for glass electrode, and change in instrument calibration. Being used in waste treatment, bleach production, pulp and paper bleaching. Suited for relatively high temperature, pressure.

14 — Electrical Conductivity

Principle	*Range*	*Acc'y (p. 288)*	*Applications and Remarks*
Fig. 141—Conductivity cells in a.c. bridge. Electrical conductivity of solution is a measure of all ions present. Cell consists of two inert electrodes placed in solution, with impressed a.c. flow to avoid polarization. Connected in wheatstone bridge circuit, this measures conductivity as resistance in comparison with bridge resistor R. For temperature compensation, alternate method uses sealed reference cell of same solution. Bridge may be self-balancing type (Section 24) often with cathode ray null indicator (Industrial Instruments, Inc.).	From as low as 0.01 ppm. dissolved solids to as high as oleum.	Usually 1% of actual concentration. Precision methods, 0.1%.	Used mainly for detecting condenser water leaks into condensate, determining exhaustion of deionizing beds. Also process applications where strength of single-component solutions is to be measured. Can be used for recording and/or alarm. Can be used (Leeds & Northrup) for determining carry-over in steam from boilers and evaporators by condensing steam.
Gas analysis by water conductivity (Davis Instruments). Conductivity of distilled water is measured before and after contact with gas sample. Circuit like that of Fig. 141, reference cell being used for distilled water, second cell for sample. Water flows through reference cell, absorber, sample cell.	Used only for gases which ionize in water.		Suitable for gases directly ionizable in water, or ionizable after being broken down by heat. Includes chlorinated hydrocarbons, carbon bisulphide, chlorine, hydrogen sulphide, sulphur dioxide, etc.

15 — Thermal Conductivity

Principle	*Range*	*Acc'y (p. 288)*	*Applications and Remarks*
Fig. 142—Double-cell, single-pass type. Heat loss from identical heated wires, one in test gas, one in standard gas, is measured in terms of resistance change. Shows relative thermal conductivity which in many binary mixtures can be expressed as composition of test gas. Conductivity varies widely for various gases.	Under favorable conditions, 0 to 100% of one gas in another.	High under favorable circumstances.	Widely used for binary gas mixtures such as CO-hydrogen, hydrogen-nitrogen, carbon dioxide-air. Now being used as measuring element in gas chromatography. For multi-component mixtures see next method.
Double-cell, double-pass type. Multi-component mixture to be analyzed for one component is passed through first cell of Fig. 142, then mixture is altered so as to change conductivity of component to be measured, by burning, absorption, etc. Finally mixture passes through second cell. Difference measures wanted component.		Can be high under favorable circumstances.	Used for example in analysis for carbon dioxide in mixture with air and CO by absorption of dioxide after first pass. These methods may use a.c. rather than d.c. bridge circuit.
Four-cell conductivity-convection type (Mine Safety Appliances Co.). To give added sensitivity this type uses a conventional cell, in which thermal conductivity is the main source of heat loss, in series with a larger diameter cell where both conductivity and convection heat losses occur. Larger cell loses heat faster, but the difference becomes greater as the thermal conductivity of the gas decreases. Method therefore amplifies the difference between, say, carbon dioxide and hydrogen.	Calibration possible over very narrow or very wide ranges.	High.	By increased selectivity it is said to be possible to analyze continuously for one component of a mixture without interference from other constituents. Hookup similar to four-cell, single-pass type (below), with one large-, one small-diameter cell on each side of bridge, sample flowing in parallel to one side, standard to other.
Four-cell, single- or double-pass type (Gow-Mac Inst. Co.). Same general method as Fig. 142 except that four cells are used, hooked up as the four arms of a wheatstone bridge.	Industrial gases suitable for thermal conductivity.	High as 16 ppm. hydrogen in oxygen.	Analysis by either single- or two-pass method. Double the usual number of cells increases response.

16 — Calorific Value, Combustible Content, Explosibility

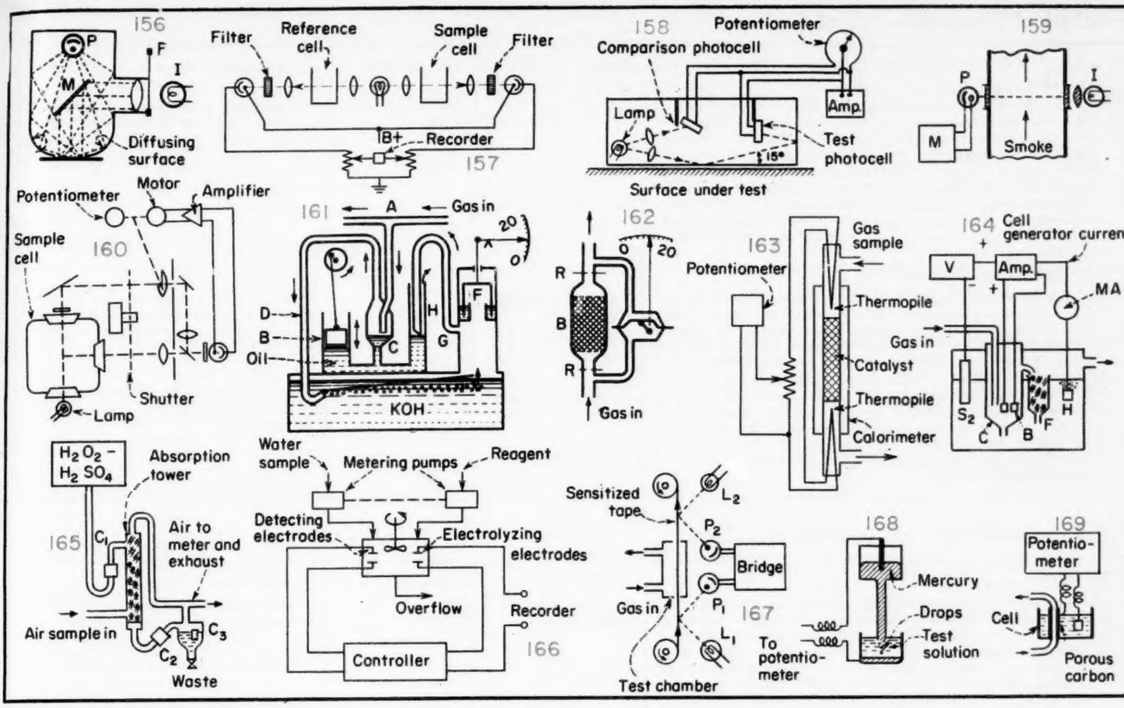
Principle	*Range*	*Acc'y (p. 288)*	*Applications and Remarks*
Fig. 143—Continuous gas calorimeter (Cutler-Hammer, Inc.). Gas is burned at constant rate, transferring heat to metered flow of cooling air. Temperature rise of air is measured by resistance thermometers T_1 and T_2, temperature difference being recorded as calorific value by self-balancing wheatstone bridge circuit.	All fuel gases.	High.	Used to record calorific value of fuel gases for inventory purposes, and to control mixing to standard calorific value.
Fig. 144—Combustible gas detectors (Mine Safety Appliance Co., also others). Heated, sensitized resistance wire in bridge circuit protected by metal gauze. If combustible gas in air contacts filament, combustion raises temperature, changes resistance, is detected by bridge. Calibrated for particular gas as % of explosive limit.	Any combustible gas or vapor.	High.	Used for detecting dangerous limits of solvent vapors, fuel gases, sewage gases, gasoline vapor, etc.
Combustible gas alarm (Mine Safety Appliances Co., others). Similar in principle to Fig. 144 except that instrument is designed for continuous sample-taking, with automatic alarm when unsafe. Sealed reference cell (c.f., thermal conductivity analysis, Section 15) adds to accuracy of circuit.	All industrial combustible gas hazards.	High.	In explosion-proof case, is used for continuous monitoring of hazardous areas. Calibrated for particular gases, but will detect any other combustible gas or vapor that may be present.
Fig. 145—Explosive gas recorder, thermocouple type (Davis Instruments). Similar in principle to type described above except that the test and standard gas filaments are heated by a.c. and their temperature rise is measured by thermocouples bonded to the heaters. Combustion raises heater temperature and thermocouple temperature, the latter (opposing) producing voltage proportional to explosibility.	Usual ranges of industrial explosive gases.	High.	Has advantage compared with wheatstone bridge method that gradual loss of Pt from the heaters does not cause zero drift of instrument. Heater temperature remains substantially constant despite loss.
Fig. 146—Combustibles analyzer (Bailey Meter Co.). Measured volume of air is added to sample gas which is then burned on a sensitized Pt filament. Temperature rise is measured as resistance change in a.c. bridge, recorded as % combustibles.	Min. span 5% combustibles, max. 0–25%.	¼% actual at lower ranges, 2% scale at higher.	Used for measuring combustibles in furnaces, kilns, atmosphere producers, chemical processes. Records and can operate alarms.

17 — Humidity of Gases

Principle	Range	Acc'y (p. 288)	Applications and Remarks
(a) Wet-Bulb Depression			
Fig. 147—Sling psychrometer. Based on measurement of wet-bulb depression. Two thermometers are fastened together. One measures dry-bulb. The other, covered with a water-saturated wick, measures wet-bulb, provided that sling is whirled to produce rapid air flow for maximum evaporative cooling. From psychrometric tables the relative humidity and dewpoint can be determined.	0 to 100% R.H.	Up to about 1%.	Most accurate simple and low-cost device for measuring relative humidity of air.
Recording psychrometer. Principle same as that of sling psychrometer except that bulbs of a two-pen recording thermometer are installed in an air-stream of at least 900 fpm. velocity. Wet-bulb wick kept saturated by water reservoir.	0 to 100% R.H.	1% or better.	Probably the most used method for recording wet-bulb, dry-bulb temperatures for industrial humidity determination. Hazard is that wet-bulb may run dry.
Direct-recording psychrometer (Leeds & Northrup Co.). Measures wet- and dry-bulb temperatures as above except that resistance thermometers are used. Bridge circuit incorporates novel arrangement reading directly in R.H. Recorder has two superposed bridge circuits, one for wet-, one for dry-bulb. If these temperatures are plotted against each other it is found that they fall on a constant R.H. line through the origin, that all combinations on this line are same R.H. Hence recorder compares measurements, finds which line they fall on and indicates result as R.H.	10 to 100% R.H.	1.5% R.H. or less.	Saves computation of relative humidity from wet- and dry-bulb readings. Simplifies automatic control.
(b) Hygrometers			
Fig. 148—Dimensional-change hygrometers. Various organic materials change in linear (or volume) dimensions with changes in relative humidity. Among them are human hair, which makes one of the most accurate hygrometers, various woods, animal membranes. Wood shaving cemented to spring made of screen wire and coiled like a bimetallic thermometer (Fig. 1) makes a simple direct-reading indicator.	20 to 90%.	2% in best units, generally rather poor.	Advantage is direct reading in R.H. Slow response and somewhat temperature sensitive.
Fig. 149—Electric resistance hygrometers (Brown, and others). Developed originally by NBS, now made by several. Double wire winding on light insulator is coated with hygroscopic film containing lithium chloride which becomes more conductive as its equilibrium moisture content increases. Ambient humidity determines conductivity of coating and this governs current flow between the wires.	35 to 93% R.H., 50 to 120F dry-bulb.	1.5% or better.	Rapid response and good accuracy are main advantages. A.c. may be used, measured as d.c. by rectifier bridge. Or resistance of element can be measured in a wheatstone bridge circuit. Can be self-compensating for temperature.
(c) Dewpoint			
Fig. 150—Mirror-type dewpoint recorder (General Electric Co., others). Mirror M in contact with flowing gas is cooled to condense vapor. Light passing through duct D from source I to photocell P is reduced as dew forms. Meter A then starts a heater H to evaporate dew. When light again increases, refrigerator R cools bath, repeating cycle. Temperature shows peaks and valleys, the valleys being dewpoint temperature. Only valleys are recorded.	From 110° F. to −100° F.	3° F.	Can measure extremely low dewpoints and so is used chiefly for determining moisture content of industrial gases.
Fig. 151—Electric hygrometer-type dewpoint meter (Foxboro Co.). Superficially resembles Fig. 149 but works on different principle. Double wire winding on insulating tube is coated with a hygroscopic conducting coating (lithium chloride solution). Inside the tube is a thermometer bulb. Low voltage current supplied to wires heats the coating, thereby driving out moisture until equilibrium is reached between moisture leaving and moisture returning. Temperature of the equilibrium point as measured by the thermometer is related to dewpoint of air at bulb.	Dewpoints of −50 to 140° F. at ambients to 220° F.	1° F.	Requires neither water supply nor refrigeration. Can be used at higher ambients without error by cooling sample to 220° F. or below before contacting bulb. Reads directly in dewpoint, grains per standard cu. ft. or percent water vapor by volume.
(d) Other			
Fig. 152—Water vapor recorder measures heat energy exchanged when a gas is adsorbed on or desorbed from the surface of a solid adsorbent (Mine Safety Appliances Co.). Gas sample is split into two equal streams, one of which is dried completely by a regenerative adsorption column. Split streams are alternately passed every two minutes through adsorption cells. Temperature at the equilibrium point is measured by differential thermopile. Cell output is measured by peak-to-peak voltmeter which is calibrated to record directly in ppm. of water vapor.	0 to 50 ppm. min. 0 to 5,000 ppm. max.	±1%.	Monitors water vapor in hydrocarbon-gas streams. Split gas streams permit alternate adsorption and desorption in each detector cell, thus regenerating desicant each cycle. The two gas streams must have constant and equal flow; also be maintained a few degrees above the highest anticipated ambient temperature.
Fig. 153—Electrolytic water analyzer (duPont design) (Manufacturers Engineering & Equipment Corp., and others). Water vapor in gas stream is continuously passed over and absorbed on a film of partially hydrated phosphorus pentoxide. The absorbed water is quantitatively electrolyzed between platinum electrodes in the detector cell. The current required for electrolysis is directly proportional (Faraday's Law) to the absorbed water. Meter A in series with the cell reads proportional to the water content of gas stream.	0 to 30 ppm. 0 to 100 ppm. 0 to 300 ppm. 0 to 1,000 ppm.	±5%.	Detects water in various inorganic gases, hydrocarbon gases and vapors, fluorinated hydrocarbons. Basic compounds such as ammonia and organic compounds such as methanol cause interference. Flow must be metered for specific gases.

18 — Moisture Content of Solids

Principle	Range	Acc'y (p. 288)	Applications and Remarks
Resistance meters (Tagliabue, others). Resistance of massive solids is read between prongs mounted a fixed distance apart, thrust into material. Resistance of pulverized materials is read by applying standard compression between plates, measuring resistance across plates. Uses wheatstone bridge circuit and indicator.			Used for powders, lumber, leather, tobacco and similar materials. Calibrated against materials of known moisture content.
Dielectric-constant meter (Tagliabue). Since water has 15 to 20 times the dielectric constant of most materials, small changes in water content mean relatively large dielectric changes. Weighed material is put into test condenser, oscillation frequency of test cell circuit is set to standard frequency as produced in a second, crystal-controlled oscillating circuit. Null position represents moisture content.	Likely range of moisture content in commercial materials.	High.	Used chiefly on seeds, grains and powdered chemicals.



Figs. 156-169—Instruments for measuring optical and chemical properties of materials.

18—Moisture Content of Solids (Cont.)

Principle	*Range*	*Acc'y (p. 288)*	*Applications and Remarks*
Fig. 154—Dielectric constant moving-web meter (Foxboro Co.). Box over moving web of moist material contains hygroscopic dielectric between condenser plates. Air in box and in dielectric attains moisture equilibrium with web material. This equilibrium and hence moisture content of web determined as capacitance in high frequency bridge.			Used extensively in paper mills to measure moisture content of paper as it progresses through paper machine.
Fig. 155—(Fielden Instrument Div.). Dielectric constant granular materials meter (developed by Rogers of The Quaker Oats Co.). Five parallel horizontal augers push material between electrode plates in test cell. Tapered walls in test cell ease flow and prevent undue pressure which may change characteristics of the material. Moisture content of material measured in capacitance bridge circuit.		0.2%, depends on particle size.	Continuously records or controls moisture content in cereal grains and other free-flowing solids of consistent particle sizes. With large quantities, a portion of main stream (about 5%) is bypassed through test cell.

19—Optical Properties

Principle	*Range*	*Acc'y (p. 288)*	*Applications and Remarks*
(a) Color			
Fig. 156—Color comparators. Used to obtain visual match of colors. First, standard is put at S and response of photocell P is obtained with white, red, green and blue light (obtained by filters at F from source I). Then sample is put through same routine. Comparable response should give visual match.			Used in matching paints, dyes, paper colors and the like. Can also compare transmission.
Photoelectric colorimeters. Many types, but in general they compare transmission of light of various colors (produced with monochromatic filters) through sample and standard. Light from an integrating sphere may be passed alternately through sample and standard, by use of a light chopper, comparative transmission being read with a photomultiplier tube. System can be balanced to non-pulsating output of photomultiplier by reducing light reaching the standard.			Used where exact transmission or reflectance of certain colors is needed for matching or record, but complete spectrophotometric curve is not needed.
Fig. 157—Photoelectric colorimeters (Milton Roy Co., and others) uses two similar photocells, passing light through sample to one cell, passing part of same light to reference cell. Cell outputs are then compared in the recorder circuit, balanced and recorded as relative transmission.			Can be used with auxiliary equipment involving colorimetric titrations for the detection in ppm. range of many compounds, e.g., silica or total hardness in water, etc.
Recording spectrophotometer (General Electric Co.). Differs from filter photometers and comparators in principle in using a spectrometer type monochromator in which monochromatic light of any desired wavelength from 400 to 700 millimicrons is produced by dispersion with prisms and a slit. This light is passed alternately through a sample and a standard, chopped to produce an a.c. if unbalanced and is then balanced by a light-polarizing prism, position of which is recorded as % transmission vs. wavelength.	Wave lengths from 400 to 700 millimicrons (1,000 is possible).	Results reproducible to 0.2%.	Used for color control for all types of colored products, enabling complete colorimetric analysis to be made and recorded. Operates automatically.

Continued next page

19—Optical Properties (Cont.)

Principle	*Range*	*Acc'y (p. 288)*	*Applications and Remarks*
(b) Other			
Fig. 158—Gloss recorder (Gardner Labs.). Measures reflectance, brightness, etc. Available in various types for measuring gloss at 20, 45, 60, 75 and 85° angles. Type shown, for beam striking surface at 75° from vertical, has one light source, two photocells. One beam (reference) is concentrated on first photocell direct. Second beam is projected on surface to be measured, reflected onto second photocell. Cell outputs are compared by a null-balance potentiometer recorder which records in % reflectance. Standard cell periodically adjusted to 100% reflectance.		Precision 2 scale units.	Used in measuring reflectance of glossy products such as coated and supercalendered paper, enamels, paints, plastics.
(c) Turbidity, Opacity			
Fig. 159—Smoke and fume density meter (Ess Instrument Co., others). Type shown uses photocell to measure light absorption by smoke in stack. Bailey Meter Co. uses a hermetically sealed bolometer (resistance thermometer) to measure reduction in heat received from a sealed beam spotlight. Null-balance recorder is compensated for temperature.	Various 0 to complete cut-off.		Used to monitor smoke stacks, measure density of white water in paper mills. May be applied to automatic combustion control.
Fig. 160—Photoelectric turbidimeter (Baird-Atomic, Inc., others). Light transmitted by the liquid in sample cell is continuously compared with light scattered by suspended particles in the stream. Phototube output, measured by recording potentiometer, varies as light is more or less cut off by suspended particles.	Various ranges such as 0.05 to 250 ppm.	±2%.	Used for monitoring turbidity, color or other light-absorption properties of process solutions.

20 — Composition by Chemical Reaction

Principle	*Range*	*Acc'y (p. 288)*	*Applications and Remarks.*
Fig. 161—Orsat gas analyzers operate by absorption of components with subsequent measure of volume at standard pressure. Automatic type shown (Republic Flow Meters Co.) measures CO_2 in flue gas. Piston B draws in sample at A, traps it in C, forces it into KOH at E. Unabsorbed gas registers in bell at F, then escapes at H. Oil motion moves and seals gas. Recorder calibrated in % CO_2.	0 to 20% CO_2; any range possible.	High.	Used chiefly for measuring carbon dioxide in stack gas for combustion control.
Fig. 162—Gas analysis by pressure drop. Gas passes through a restriction, an absorption chamber and another restriction in series. Differential pressure across the restrictions is measure of % of gas absorbed.	0 to 50% approx.	Moderate.	Has been used chiefly for carbon dioxide.
Fig. 163—Oxygen analyzer (Baker & Co., Inc.). Oxygen as an impurity in gas streams is catalytically oxidized in a calorimeter with excess hydrogen. The heat liberated is directly proportional to the oxygen content. A thermopile, with cold junction located ahead of the catalyst and hot junction in gas stream emerging from catalyst chamber, indicates temperature rise which is a measure of oxygen content.	0.001 to 1% oxygen 0.002 to 2% hydrogen.	±2%.	Detect small quantities of oxygen as an impurity in inert gases, carbon dioxide, hydrogen or saturated hydrocarbon gases. Hydrogen (and oxygen) for the analysis is generated by an electrolytic cell within the instrument.
Trace amounts of oxygen in gas streams are also detected by colorimetric differential-photometer method (Consolidated Electrodynamics Corp.). An oxygen-sensitive reagent produces a proportional color change in the gas sample containing oxygen. A colorimeter similar to Fig. 157 measures the optical transmittance between the oxidized and reduced reagent and determines the amount of oxygen.	0 to 50 ppm. 0 to 1,000 ppm.	±2%.	Detects trace amounts of oxygen in polymerization processes, fluid catalytic cracking processes, hydrogen and inert gases.
Potentimetric titration. Neutralization and other endpoints determined by suitable indicating and reference electrodes. Potentiometer controls cut-off.	Any.	0.5% or better.	Used in laboratory work but could be adapted to automatic analysis and control.
Fig. 164—Bromine titration for sulphur gases (Tritrilog: Consolidated Eng. Corp.). Automatic titrator for mustard, other sulphur gases. Gas enters titration cell C, is titrated with bromine generated by current between electrodes H and B. Production of bromine controlled by sensing electrodes S_1 and S_2 and opposed reference voltage V (calomel electrode). Excess of sulphur increases potential and output of d.c. amplifier A to increase bromine production and so balance sulphur admission. Sulphur content recorded in terms of electrolysis current by meter Ma.	Concentration as low as 0.1 ppm.	High.	Used to record low concentrations of sulphur-containing gases such as mustard, mercaptans, SO_2, H_2S.
Fig. 165—Sulphur dioxide by electrical conductivity (Thomas Autometer: L & N). SO_2 in air is absorbed in sulphuric acid and hydrogen peroxide. Electric conductivity is measured before and after absorption cell by conductivity cells C_1 and C_2. Increase, depending on SO_2 converted to sulphate, is recorded as % SO_2. Spent solution accumulated in reservoir measured periodically by C_3 for integration of SO_2.	0 to 5 ppm. SO_2.	Accurate to better than 0.1 ppm.	Used in determining low concentrations of SO_2 in atmosphere.
Fig. 166—Residual chlorine analyzer (Leeds & Northrup). Sample stream of water mixes with stream of reagent (solution of sulfuric acid and ferric sulfate) in the presence of two pairs of electrodes—one carrying electrolyzing current, the other serving as a detecting system. Electrical current causes titration between reagent and chlorine residuals; any unbalance causes detecting electrode to initiate a signal which throttles the current. Current flow proportional to chlorine.	0 to 2 ppm. 0 to 20 ppm.		Used in control of chlorine content in water. Not affected by pH, temperature or salt content of water.
Fig. 167—Hydrogen sulphide by color change (Rubicon Co.). Photocells P_1 and P_2 continuously scan sensitized tape for darkening of lead acetate by H_2S. Cells are connected into bridge circuit B for continuous record as H_2S.	Suitable for low concentrations.	High.	Same principle can be applied to other gases where suitable color change is available. Similar method used by G.E. for Hg vapor.
Gas testers (Mines Safety Appliances Co.). Visual color change testers made for CO, aromatic hydrocarbons, hydrogen sulphide using suitable reagents impregnated into silica gel. Color change compared with color scale gives %.	CO from 10 to 1,000 ppm. H_2S from 25 to 400 ppm.		Light-weight portable unit for manual use in detecting conditions within working areas and process vessels.
Fig. 168—Polarigraph. Uses dropping mercury as a continuously renewable electrode on which various ions plate out as potential increases. Record forms step-like curve which indicates substances by position of step, quantity by height.	For trace element analysis as well as large concentrations.	Measures down to 10,000ths of 1%.	Primarily a laboratory instrument for quick, automatic analysis, especially trace elements in plating, organic chemicals, lube oil and explosives.

20—Composition by Chemical Reaction (Cont.)

Principle	*Range*	*Acc'y (p. 288)*	*Applications and Remarks*
Fig. 169—Polarizing-cell oxygen analyzer (Mine Safety Appliances Co.). Gas passes through a porous carbon tube which is one electrode in a cell containing a special electrolyte and a second, metal electrode. Cell generates current and polarizes on carbon electrode. Oxygen diffusing through carbon depolarizes cell. Current output therefore depends on % of oxygen. Recording potentiometer records % O_2.	Various ranges such as 0 to 1.0%, up to 0 to 25%.	2% of scale.	General use for recording oxygen concentration.

21 — Composition by Spectroscopy

Principle	*Range*	*Acc'y (p. 288)*	*Applications and Remarks*
(a) Emission			
Fig. 170—Arc or spark (emission) spectroscope. At high temperature of arc or spark, material to be analyzed gives off characteristic radiations at different wave lengths. Light can be dispersed by prism (or diffraction grating), producing characteristic line spectrum which can be photographed, or individual lines segregated by a slit for viewing.	About 2,000 to about 9,000 Angstrom units.	Depends on quality of optics.	Chemical analysis, especially of metals and alloys, astronomy for element identification. Can identify trace elements down to billionths of grams. Most emission spectroscopy is by grating spectrograph.
Fig. 171—Emission spectrograph, direct-reading (Baird-Atomic, others). Concave diffraction-grating spectrometer with spark or arc source, and movable exit slits. Light passing slits is focussed by concave mirrors onto photomultiplier tubes which charge condensers in proportion to intensity of each line (concentration of element). Condenser charges measured by electric clocks, one for each element, calibrated in % of element present.	2,800 to 4,300 A. (2nd order spectrum).		Used for metal and alloy analysis for number of elements to suit. Extremely fast, about 5 min. from sampling to report.
Fig. 172—Flame photometers (Perkin-Elmer Corp., others). Sample sprayed into gas flame gives characteristic light which passes through entrance slit E_1, through optical system of prisms and lenses, to beam splitter where part goes to movable exit slit E_2, thence to photocells P_1 and P_2. Other part through fixed slit E_3 to standardizing cell P_3. Red and blue sensitive cells measure intensity of characteristic lines with aid of movable slit E_2.	Na, K, Li, Ca, Sr and other metals; 3 to 1,000 ppm. depending on metal.	1 to 2%.	Primarily a laboratory instrument for rapid analysis for sodium, potassium, lithium and other metals in mixtures. Good for trace elements. Time less than 2 min. per element.
(b) Infrared Absorption — Dispersive Types			
Fig. 173—Infrared absorption spectrometer, single-beam type (Perkin-Elmer Corp., others). Radiation from SiC glower is focussed by mirrors onto sample cell, then passes through entrance slit to collimating parabolic mirror which reflects onto prism. Radiation dispersed by prism is reflected by movable wavelength mirror back through prism and parabolic mirror and eventually through exit slit and mirrors to thermocouple. Intensity of narrow frequency band selected by wavelength mirror is then measured. As spectrum is scanned, recorder plots intensity vs. wavelength.	2 to 40 microns depending on prism material. 2 to 15 microns with NaCl prism.	High.	Used for analysis of organic materials in solid, liquid or vapor state. Same principle has been used in a continuous product-stream recorder for six components measured in a 5-min. cycle.
Fig. 174—Infrared absorption plant-stream analyzer (Perkin-Elmer Corp.). Used for continuous analysis of single component in process stream. Is set to measure any two infrared wavelengths simultaneously. One is region where component of interest absorbs strongly, other where it does not. Two measurements are ratioed and reported as percent of component. Source radiation is chopped mechanically into two beams 180° out of phase and of slightly different path. Beams alternately pass through sample cell and through a reflecting system and slit. Both beams pass through a prism and are reflected by separate Littrow mirrors along different paths back through the prism and reflecting system to a detector thermocouple. If beams are alike, there is no signal; if different due to different absorption, a.c. results, is amplified and drives a servo to attenuate and null reference beam. Attenuator position reports as sample composition.	Depends on application.	Depends on application; reproducibility usually within 1% of scale.	Used in plant liquid or gas streams for analysis or determining course of a reaction. Suitable for liquids requiring extremely thin sample cells.
Infared absorption spectrometer, double-beam type (Baird-Atomic, others). Essentially similar in principle to type described in Fig. 173 except that initial beam is split to pass through both sample and a compensator cell or standard. Any unbalance is nulled, recorded as % absorption vs. wavelength.	Full useful range of optics.	High.	Used mainly in high-precision organic research.
(c) Infrared Absorption—Non-dispersive Types			
Fig. 175—Infrared analyzer, non-selective or negative type (Baird-Atomic, others). Where spectrometers use monochromatic radiation, analyzers use all radiation from about 1 to 15 microns. Two general types, non-selective which uses two steady beams, and selective (below) which uses chopped radiation. Non-selective (Fig. 175) passes radiation through two lines, one containing sample S and filter cell F, other containing sample S and compensator cell C. Filter contains 100% of component analyzed for, compensator other gases in mixture not analyzed for. Interference cell I is used sometimes to desensitize to interfering gas. Comparison of radiation received by bolometers is indicative of % of gas for which analyzed if various cells are properly sensitized.	Single hydrocarbon vapors in certain combinations. Also other gases.	High.	Used for continuous plant stream analysis, for example, on methane in illuminating gas, acetone in air, isobutane in normal butane and other hydrocarbons. Also can be used for sulphur dioxide, water vapor in low concentrations, carbon dioxide and monoxide, etc.
Fig. 176—Infrared analyzer, selective or positive (Luft) type (Mine Safety Appliances Co., others). Similar to non-selective type Fig. 175 in using wide range of radiation. However, differs in that beams alternate through two sides, the sample S and compensator cell C are not in series, and a different type of detector is used. Detector is a condenser microphone receiving pressure fluctuation from alternating beams combined in V which is filled with non-absorbing gases. D is filled with gas analyzed for, compensator C usually with non-absorbing gas. Null balance adjusts source on compensator side to give equal response both sides, difference in radiation being recorded as % of gas analyzed for.	Single gases including hydrocarbon vapors in certain combinations.	High.	Used for continuous plant stream analysis similar to non-selective type.

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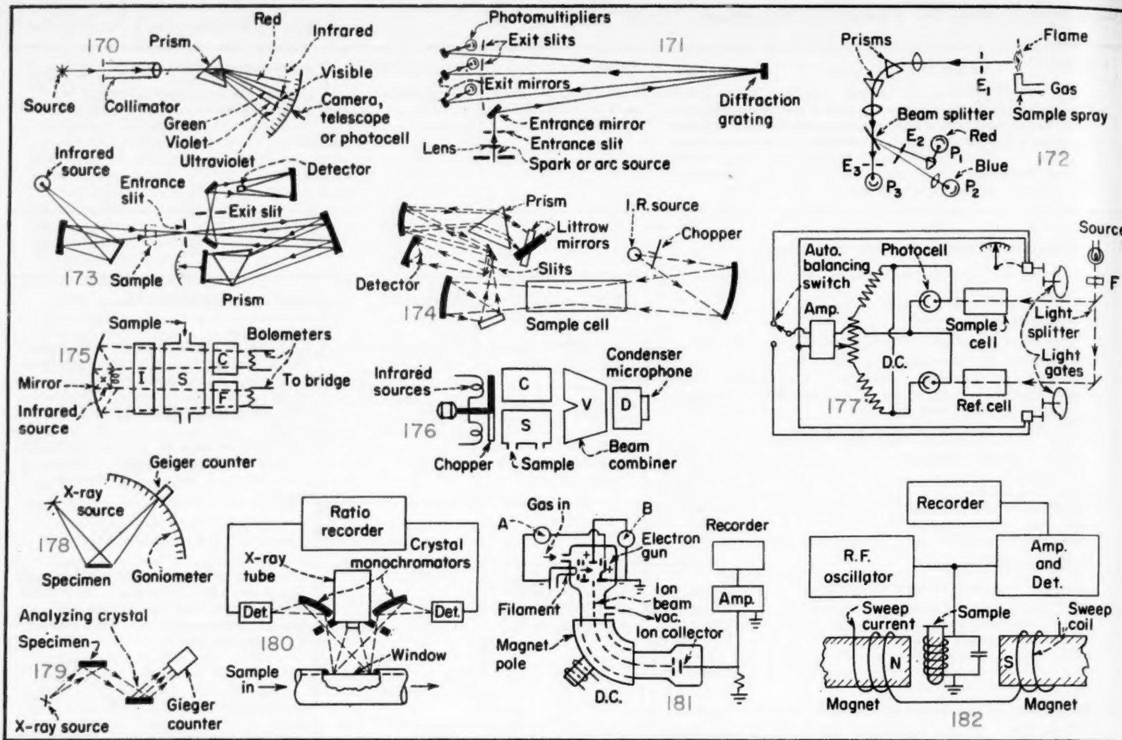

Figs. 170-182—Instruments for determining composition by spectroscopic and other properties of materials.

21 — Composition by Spectroscopy (Cont.)

Principle	*Range*	*Acc'y (p. 288)*	*Applications and Remarks*
Three-beam infrared analyzer, positive type (Tri-Non, Perkin-Elmer Corp.). Essentially similar to Fig. 176 except that nulling is accomplished by optical attenuator. Severe interference can be compensated by using a third beam.			
(d) Ultraviolet and X-Ray Absorption			
Ultraviolet spectrometer (Beckman Instruments, Inc., others). Radiation from hydrogen discharge lamp passes through entrance slit to collimating mirror, thence through quartz prism to reflecting backing, and back through the prism and collimating mirror to exit slit above entrance. Passing through sample cell it reaches phototube where intensity is measured for various wavelengths. Rotating quartz prism supplies monochromatic radiation of various wavelengths from 0.2 to 1.0 microns. Recorder records transmission intensity vs. wavelength.	0.2 to 1.0 microns.	Reproducible to 0.02 millimicrons in U.V.	Analysis of liquid and gaseous materials such as vitamin A, butadiene, toluene molecules containing benzene rings, ethylene and carbonyl structures, etc. With flame attachment, becomes a flame photometer.
Fig. 177—Non-dispersive ultraviolet analyzer (Manufacturers Eng. & Equipment Co., others). In DuPont design shown, light of desired wavelength (range 0.22 to 1.2 microns) is selected by optical filter F, then split into two beams, one passing through sample cell, other through reference cell. Use of two beams eliminates effect of cell window deposits by having thin section of sample as reference, thicker section for "sample." Sample passes through both. Unabsorbed light passed through cells falls on opposed photocells in bridge circuit, any unbalance driving a servo motor to move light gate in sample path to restore balance. Where window fouling is unlikely, only a single cell, in sample path, is used, the reference beam falling directly on its phototube.	0 to 100% composition, down to 0 to 1 ppm. for some materials.	High.	Less selective but more sensitive than infrared analyzers. Used in determining many organics, chlorine, sulfur dioxide, nitrogen dioxide, etc.
X-ray photometer (General Electric Co.). X-radiation passed through sample is partially absorbed. Transmission is recorded as % of unknown compared to standard.	Various chemicals in presence of others.	0.2%.	Analysis independent of physical form of material analyzed. Used for sulphur in plastics, tetraethyl lead in gasoline, sulphur in oil.
(e) Fluorescence and Diffraction			
Fig. 178—X-ray diffraction spectrometer (Philips Electronics, Inc.). X-ray beam striking sample gives off a cone of secondary rays, intensity of which at different radii varies with atomic structure. Can be photographed to give characteristic concentric-ring patterns. Instead, for recording, a cross section of the diffraction cone is scanned by a Geiger counter moving along an arc (goniometer).	Unlimited. No two materials show identical patterns.	High.	Used in atomic structure study and in identification of materials by comparison with known patterns. Since crystal structure is shown, can be used, for example, in distinguishing between rutile and anatase phases of titanium dioxide.
Electron diffraction. Similar to X-ray diffraction. Electron beam directed on sample produces a diffraction pattern which can be photographed.	Thin films of ceramics, metals, plastics.	High.	Used chiefly for study of surface conditions. X-ray diffraction operates on internal structure.
Fig. 179—X-ray fluorescence spectrometer (Philips Electronics, Inc.). X-radiation causes some elements to give off characteristic individual radiations. These are collimated, analyzed by a crystal which, by its position, reflects individual radiations at specific angles. Intensities measured by Geiger-counter goniometer.	Analyzes for elements.	High.	Differs from X-ray diffraction in that it gives results characteristic of elements present in sample, rather than atomic structure. Suitable for metals, alloys, minerals, chemicals, mixtures and compounds.

21—Composition by Spectroscopy (Cont.)

Principle	Range	Acc'y (p. 288)	Applications and Remarks
Fig. 180—X-ray fluorescence continuous analyzer (Applied Research Labs.). Method originally used for control of tin-plate thickness now adapted to continuous solid or liquid streams. X-rays falling on sample produce characteristic radiations which are picked up by curved crystal monochromators. One for reference diffracts only scattered radiation of a chosen wavelength, the other a wavelength characteristic of element being analyzed. Diffracted beams fall on separate Geiger counters whose output is ratioed and recorded as concentration.	Used for elements, applicable on atomic number 19 (K) and higher.	Highly selective.	Various analyses such as metals in ores, in plating solutions, in catalysts.
Raman spectrograph (Applied Research Labs.). High intensity light beam passing through sample causes light scattering, scattered portion emerging with different and characteristic wave lengths (Raman spectrum). Various compounds produce typical line patterns when dispersed by a collimating system and series of prisms. This spectrum can be photographed, or scanned by moving exit slit to allow a photomultiplier to measure and continuously record line intensities vs. wavelength.	Many inorganic and most organic compounds.	High.	Used for qualitative and quantitative analysis and for study of structure. Can be applied to liquids, solids and gases. Can be used for aqueous solutions which could not be analyzed by infrared owing to water absorption.
(f) Mass Spectrometry			
Fig. 181—Mass spectrometer, continuous spectrum type. Specimen gas at low pressure enters tube where high velocity electrons produced between filament and plate by electron accelerating voltage A strike molecules and produce ionized molecules and molecular fragments which are accelerated into tube by voltage B. Ions enter field of a magnet which curves their paths proportional to mass. Individual masses can be focussed by varying ion-accelerating field, to enter slit and discharge at ion collector. Ion current is amplified and recorded vs. accelerating voltage in terms of mass number. Different materials give characteristic mass peaks which are analyzed mathematically to find composition.	Materials that can be vaporized. Mass numbers from 1 to 300.	Very high.	Coming into use in analytical product control of various kinds, both organic and inorganic. Uses include isotype tracer work, micro analysis. Peak heights define concentration.
Mass spectrometer, restricted span type. (Consolidated Electrodynamics Corp.). Similar in principle to above but designed to scan a limited number of mass peaks for continuous product analysis.	Can be tuned to limited number of desiredcharacteristic peaks.		Instruments operating in petroleum industry. One installation monitors a plant stream for small % of ethane.
Mass spectrometer, leak detector type. Simplified mass spectrometer tuned to helium and used with a helium gas probe to quickly locate leaks in pressure systems.	Leaks too small for other methods.	High.	First used in testing tightness of equipment in atomic bomb plants.
(g) Radio Frequency Spectrometry			
Microwave absorption. Microwaves in range from 17,000 to 28,000 megacycles are sent through wave-guide tube where absorption in gas takes place. Emergent energy is detected by crystal detector, amplified and put on oscilloscope. Absorption at various frequency bands (about 50 mc. wide) is characteristic of various materials.	High precision.		Laboratory method too complex at present for plant use. No commercial equipment available.
Electron paramagnetic resonance. Solid or liquid sample is exposed to microwave energy while in a fairly strong magnetic field. Energy absorption takes place if unpaired electrons exist in atomic electron shells. Laboratory models only available.			Samples detectable by EPR include alkali and iron group metals, rare earths, some heavy metals, molecular oxygen, nitrogen oxides, free radicals.
Fig. 182—Nuclear magnetic resonance (Schlumberger Well Surveying Co., others). Most rapidly developing method of r.f. spectroscopy. About 100 element isotopes absorb r.f. energy when in a magnetic field, due to magnetic moment and spin of atomic nucleus. In magnetic field these precess like miniature gyroscopes with a definite frequency. Sample tube in field of magnet is surrounded by a coil supplied by an r.f. generator. By sweeping magnet current through the nuclear-resonant value, energy absorption occurs. Plot of energy absorption vs. magnetic field strength gives NMR spectrum. Area under each peak is measure of quantity of that particular nucleus present.	Applicable substances.	0.1% or better.	Accurate measurement of moisture in solids, even those containing hydrogen. Product identification in petroleum and chemical industries. Detecting H, F, Li, P. Identifying groups in complex molecules.

22 — Composition by Other Physical Properties

Principle	Range	Acc'y (p. 288)	Applications and Remarks
(a) Oxygen by Magnetic Susceptibility			
Fig. 183—Magnetic susceptibility, non-uniform field type (Arnold O. Beckman, Inc.). Except for NO, oxygen is unique among gases in being attracted into magnetic field. In a non-uniform magnetic field a light test body tends to be pushed from field if O_2 is present. Displacement increases with O_2 concentration and can be measured with light ray on scale, or null-balance method can be used to record. Here a plate with fixed d.c. potential draws charged test body back to zero position when balance bridge applies proper charge. Balance bridge operates from light beam on photocells P_1 or P_2 as test body position changes. Bridge balance is therefore measure of O_2 concentration.	From few ppm. O_2 to 100%.	1% for ranges over 1% O_2.	Used specifically for analysis of gas mixtures for oxygen.
Fig. 184—Magnetic susceptibility, thermal circulation method (Leeds & Northrup, others). Operates on same property as above, but different principle. Two thermal conductivity cells are installed on sample line, receiving oxygen by diffusion. They are connected into a wheatstone bridge circuit. One is in a magnetic field. Hence oxygen is drawn up into the cell where heat from the cell resistance element heats it, reducing paramagnetic property and causing increased circulation with new oxygen entering. Thus difference in heat loss of two cells is a measure of oxygen concentration.	0 to 5% oxygen or higher.	±1.5% of full span, with max. of 0.15% oxygen.	Used specifically for analysis of gas mixtures for oxygen.

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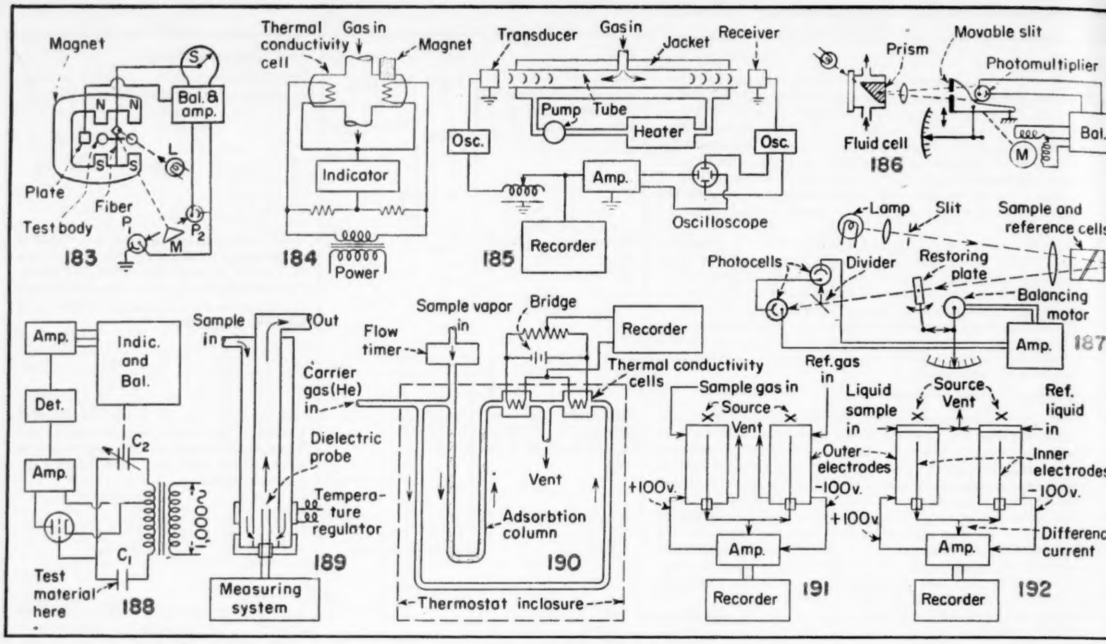

Figs. 183-192—Instruments for determining composition by chromatographic, sonic and other properties of materials.

22—Composition by Other Physical Properties (Cont.)

Principle	*Range*	*Acc'y (p. 288)*	*Applications and Remarks*
(b) Sonic Velocity			
Fig. 185—Sonic gas analyzer (National Inst. Labs.) Acoustic waves travel at widely varying speeds in various gases. Merck design shown has a long water-jacketed tube through which gas flows both ways from center to eliminate gas velocity effect. An oscillator at one end generates sound waves which are received by a crystal transducer at other end. Phase of received wave is compared with that at sender. Phase shift is precise measure of sonic velocity.	Wide range.	Sensitive enough to detect 0.005% oxygen in air, or 0.00061% hydrogen.	Method gives rapid response, does not need removal of gas from pipeline for analysis. May be especially useful for corrosive or radioactive gases. Requires accurate control of gas temperature. Non-selective so is probably limited to binary or pseudo-binary mixtures.
(c) Index of Refraction			
Fig. 186—Automatic refractometer (Precision Sci. Co.). Index of refraction is a unique property of pure materials and under favorable circumstances may be used for analysis, as in two-component mixtures. Monochromatic light enters sample cell along face of prism, is refracted through prism on path depending on refractive index of sample. Slit interposed in front of a photomultiplier tube is driven to position of emergent beam by balancing motor operated from tube output. Slit position is multiplied, recorded as refractive index.	Clear liquids of 1.32529 to 1.54409 refractive index.	3–4 in last decimal place.	Clear liquids; records, can be adapted to control.
Fig. 187—Process refractometer (Barnes Eng. Co., others). Where Fig. 186 showed a single-beam refractometer, several commercial types including Fig. 187 use a double beam to enable the instrument to be nulled. Light from a mercury arc is collimated and passed through a differential-prism cell, reflected and passed again through the cell. Half the cell contains a standard reference liquid, the other half the flowing process stream. Any change in refraction of the process stream compared with the standard causes the light beam to deviate. The beam is split, half going to one photocell, half to the other. With equal sample and standard liquids, both cells are illuminated equally. If they are unequal a signal results from the electrically opposed photocells, the signal is amplified and drives a servo motor to restore balance by turning a restoring plate ahead of the beam splitter. Restoring plate position reported as comparative refractive index.	Transparent liquids.	Limiting sensitivities down to 0.0001, 0.00001 or 0.000002 refractive index.	Binary liquid mixtures or those approaching binary. Widely useful with organics, inorganics. Gives instant response.
(d) Dielectric Constant			
Fig. 188—Dielectric constant (Foxboro Co.). Dielectric constant can be used in some cases to measure water content of liquids, and may be useful in determining composition of mixtures not containing water. Dielectric constant is a unique property of materials. For liquids, a condenser of two concentric tubes in the liquid flow line is installed in a high-frequency bridge circuit in which the balance condenser is automatically adjusted to null the detector. For solids, the hook-up is similar but the problem of controlling the weight of material in the condenser is not as simple as with liquids.			Polar in non-polar liquids, especially water in various chemicals. Temperature compensation is usually necessary.
Fig. 189—Dielectric constant chamber (Hallikainen Instruments). Cut shows probe chamber built like a heat exchanger to recover outgoing heat in incoming stream, with careful temperature control via a temperature regulator and electric heater. Liquid flows through dielectric cell portion in bottom where a 7 mc. r.f. current supply in a capacitor bridge circuit, with balancing motor, measures dielectric constant. Output is converted to 3–15 psi. air.	Full scale range greater than 1% or 1 part in 1,000.		Analyzing for polar in most non-polar liquids, e.g., methyl ethyl ketone in toluene-benzene; water in acetone; isopentane in pentane, water in phenol, isopropyl alcohol, ethylene chloride, etc.

Principle	*Range*	*Acc'y (p. 288)*	*Applications and Remarks*
(e) Gas Chromatography			
Fig. 190—Gas chromatography (Beckman Instruments, others). Watts-Carbide design shown. This former lab method is rapidly going into plant stream applications. Method depends on adsorption of stream vapor components in a chromatographic column, followed by their being swept out one by one by a carrier gas, followed by analysis separately for each component. Method is semi-continuous only, requiring from about 5 to about 30 min. per sample, depending on complexity and other factors. Plant units operate automatically, however. In Fig. 190 a controlled quantity of gas mixture is swept into the column (packed with an adsorbent solid or an inert solid coated with absorbent liquid) by means of a carrier gas, usually helium. Sample flow ceases but carrier flow continues, first sweeping out least firmly held component, followed in turn by others more strongly held. Sample-carrier flow passes through one cell of a thermal conductivity bridge, with pure carrier as reference passing through other cell.	Lower limit about 1 ppm.	Precision ½ to 2% of full scale.	Lab and plant models available for analysis of many gases and low-boiling liquids in petroleum refining, natural gas production, LPG, plastics, refrigerants, other chemicals. Separates close-boiling materials, can handle light gases including rare gases. Up to eight components can be separated and measured, each showing as an identifiable peak on the chart recording bridge output.
(f) Radiological Methods			
Fig. 191—Radiological gas analyzer (Hallikainen Instruments). Gas composition within an ionization chamber used for measuring nuclear radiations has a marked effect on the ion current. This can then be used for analyzing certain binary or pseudo-binary gas mixtures. Method has been used for determining argon in ammonia plant circulating gases, after removing ammonia and hydrogen. Different gases give widely varying ion currents, but mixtures must be calibrated, not giving predictable results. Instrument uses two temperature-controlled ionization chambers, with sample passing through one, other containing a reference gas such as nitrogen. A Sr-90 source for each cell ionizes gas, giving a difference current which is amplified and recorded as percent of the constituent measured. Shell Development design.		±1% absolute on 0-5% argon.	Has been used for both argon and ammonia. Is claimed to be both sensitive and accurate, although non-specific.
Fig. 192—Beta-ray hydrogen meter (Hallikainen Instruments). Instrument is similar in construction to Fig. 191 except that a liquid sample cell is built into one end of ionization chamber between Sr-90 beta source and chamber proper. Chemically bonded hydrogen in organic liquids has strong absorption for beta particles. However, betas are also used for thickness and density measurements (Section 8 and 9) so for measuring hydrogen, density must be constant. Two cells are temperature-controlled, one containing reference liquid, the other the sample. Difference current depends on relative beta absorption and can be recorded in terms of hydrogen content of sample.		±0.1% absolute.	Can determine percent of hydrogen in hydrocarbon and other organic liquids (if small corrections are applied for oxygen, sulfur and other heavier elements. If composition is constant it can be used to determine density within ±0.0002 grams per ml. A somewhat similar instrument (Central Sci. Co.) has a built-in density balance.
(g) Other Methods			
Gaseous conduction (General Electric). Potential difference applied to heated cylinder surrounding a central wire electrode will give variable current flow depending on conductivity of contained gas.			Basis of G. E. organic halide leak detector.
Btu. meter (Bristol Co.). Device combining flow rate through a process, with heat released or absorbed, can be used not only for controlling heat input or output, but in some cases can be used to infer composition or rate or progress of a reaction. Heat rise or fall across process is measured with series resistance thermometers. Flow rate is measured and converted to position of a contact in a self-balancing bridge measuring delta T. Recorder measures product of flow times delta T, or rate of heat release or absorption.			Semi-works and plant reaction control. Instrument can be arranged to integrate Btu. input or output.
Boiling point and melting point. Used as fundamental method in determining purity of single components.	Wide application.	Can be very precise.	Chiefly a laboratory method.

23. Electrical Quantities

Voltage—(a) Direct Current

General: This section deals mainly with those electrical instruments that are used as parts of, or in connection with, process instruments. It makes no attempt to cover electrical instruments exhaustively. In understanding the individual instruments, it should be noted that in most cases they actually measure current, regardless of the quantity in which the dial is calibrated. Most voltmeters are therefore similar to certain ammeters, except for being of higher resistance and connected across the line, rather than in the line.

Fig. 193—Permanent-magnet, moving-coil voltmeter (or ammeter). So-called D'Arsonval type, used for d.c., has a light coil connected across potential to be measured, within field of a permanent magnet. When current flows reaction of field produced by coil with field of magnet causes rotation against a calibrated spring. Used for ranges from very low to very high. Galvanometers are instruments of this type.

Fig. 194—Electrodynamic voltmeter. Has two stationary coils and a moving coil, all in series. Reaction of the fields of stationary and moving coils on current flow causes rotation vs. a calibrated spring. Not much used.

Fig. 195—Balance against a known potential. This method, the null potentiometer, is one of the most used electrical measuring methods of process instrumentation. In its simplest form, as in the sketch, a potentiometer consists of two circuits containing sources of potential which have a common branch. When the position of the sliding contact on the slide wire is set for no current flow through the galvanometer, the voltage drops from the two sources are equal. To standardize the battery in the upper circuit a standard cell is inserted in the lower branch and R is adjusted to give zero current flow when the slider is at some standard position. Then when an unknown voltage such as that from a thermocouple is substituted for the standard cell, the null position of slider on slide wire will show whether the unknown is greater or less than that of the standard. Furthermore, the slide wire can be calibrated to show how much greater or less.

Fig. 196—Vacuum tube voltmeter. Used where a high-resistance voltmeter is needed. Circuit shown in figure uses two three-element tubes, is good for ranges from 1 to about 1,200 v.

Voltage and Frequency—(b) A.C.

Fig. 197—Rectifier bridge. Enables a d.c. voltmeter to be used for a.c. by connecting four dry-type rectifiers in a bridge so that, whichever way the instantaneous current is flowing in the line, it always flows in the same direction through the meter. The arrangement is a so-called full-wave rectifier.

Fig. 198—Frequency meter. Left half of off-center aluminum disk is acted on by induction voltmeter element 1 in series with resistance, gives constant torque at all frequencies. Right half acted on by element 2 in series with a reactance. It has opposite torque but is affected by frequency which on increasing reduces current so disk turns to right to balance.

Electrodynamic voltmeter. (See again Fig. 194). Is more useful as an a.c.

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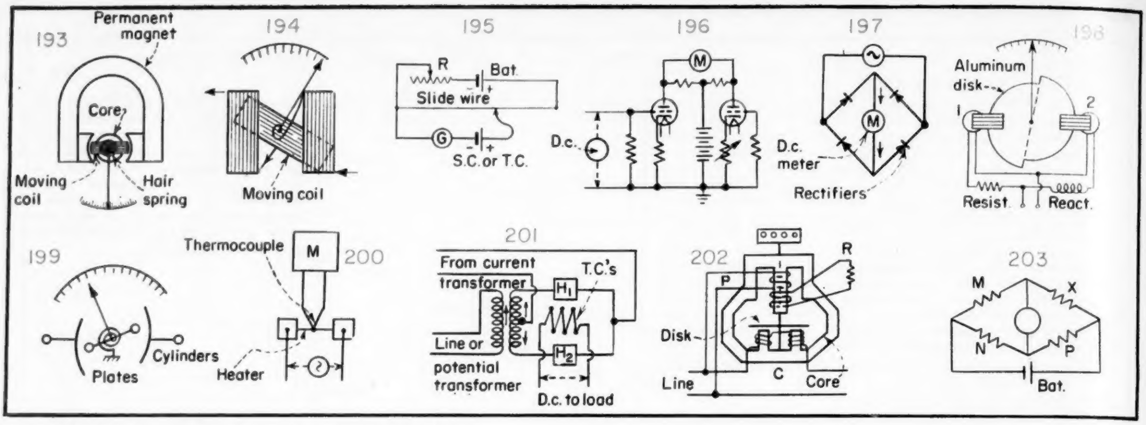


Figs. 193-203—Instruments for electrical properties.

23. Electrical Quantities (Cont.)

voltmeter than for d.c., since torque remains in same direction regardless of direction of current flow.

Fig. 199—Electrostatic voltmeter. Draws almost no current. No connection is made to the moving element. With line across the outer plates, light cylinders on the moving element are oppositely charged at any instant and thereby attracted. Charges change polarity as the current reverses so that torque remains in same direction. Can be used for extremely high voltage, either d.c. or a.c.

Electromagnetic moving iron voltmeter. This principle is used in most a.c. voltmeters and ammeters for power frequencies. Made in several forms, its simplest type is a soft iron core which is "sucked" into a coil carrying a current due to the field produced by the coil. Polarity induced in the iron reverses at each alternation so that alternating current can be measured.

(c) Current

Current measurement. As noted above, current measurement devices are in general similar to voltmeters and so will not be detailed further, except for one unique type.

Fig. 200—Thermocouple ammeter. This device makes use of a heater through which the current flows. Heat produced is independent of whether the current is direct or alternating, high or low frequency. This heat is measured by a thermocouple which produces a voltage proportional to the current (heat) and is measured by an ordinary d.c. millivoltmeter or potentiometer.

(d) Power and Energy

Power measurement, dynamometer-type meter. Power in watts is commonly measured by an instrument similar to the electrodynamic voltmeter (Fig. 194) in which, however, the stationary field coils are in series with the load and the moving armature coil is shunted across the line. Hence, one measures current, the other potential, and the combination watts.

Fig. 201—Power by thermal converter. This device resembles the thermocouple ammeter but its output is proportional to power consumed by a load and can be telemetered for long distances. Potential leads, connected across the line, are connected to the primary of a transformer. Leads from a current transformer are connected into a bridge circuit so that current in one side of the bridge is added to by current induced in the transformer, while current in the other side is opposed by transformer current. Hence the heat from heaters H_1 and H_2 will be different, depending on the load, and their average, determined by the series thermocouples, will be proportional to the load.

Fig 202—Energy consumption: the induction watthour meter. Commonest type of a.c. device for integrating watt consumption over a period of time, this meter consists of a potential winding P on an iron core, with current windings C. The armature is an aluminum disk with shaft behind the core. Interaction of flux produced by the three poles with the induced eddy currents in the disk causes rotation proportional to power. Adjustment of phase relations is obtained with a compensating winding and external resistance R. Revolutions counted by the register represent watthours.

(e) Resistance

Fig. 203—Wheatstone bridge. One of the commonest circuits used in process instrumentation. Its purpose is to determine an unknown resistance such as that of a resistance thermometer in terms of three resistances. Known resistances M, N and P are connected, together with the unknown X, in a network as shown, with a galvanometer across one diagonal and a source of d.c. (or a.c.) across the other. M and N are commonly equal but, in any event, $X = P \times M/N$ so that, if a known value for P can be chosen which will show no current flow through the galvanometer, then X can be calculated. Commonly such a circuit is used with some system for adjusting P automatically and continuously to give a null galvanometer deflection.

24. Measuring Methods

General

This section deals with the measuring devices that are used to convert the output of electrical industrial instruments into forms that can be used to operate a recorder, indicator or controller. It deals with measurements of potentials, resistances, capacitances or inductances. Such measurement methods are used with resistance thermometers, thermocouples, thermal conductivity cells, electrical conductivity cells, pH and redox cells; with strain gages and many position-measuring transmitting devices; and with a vast number of other types of instruments.

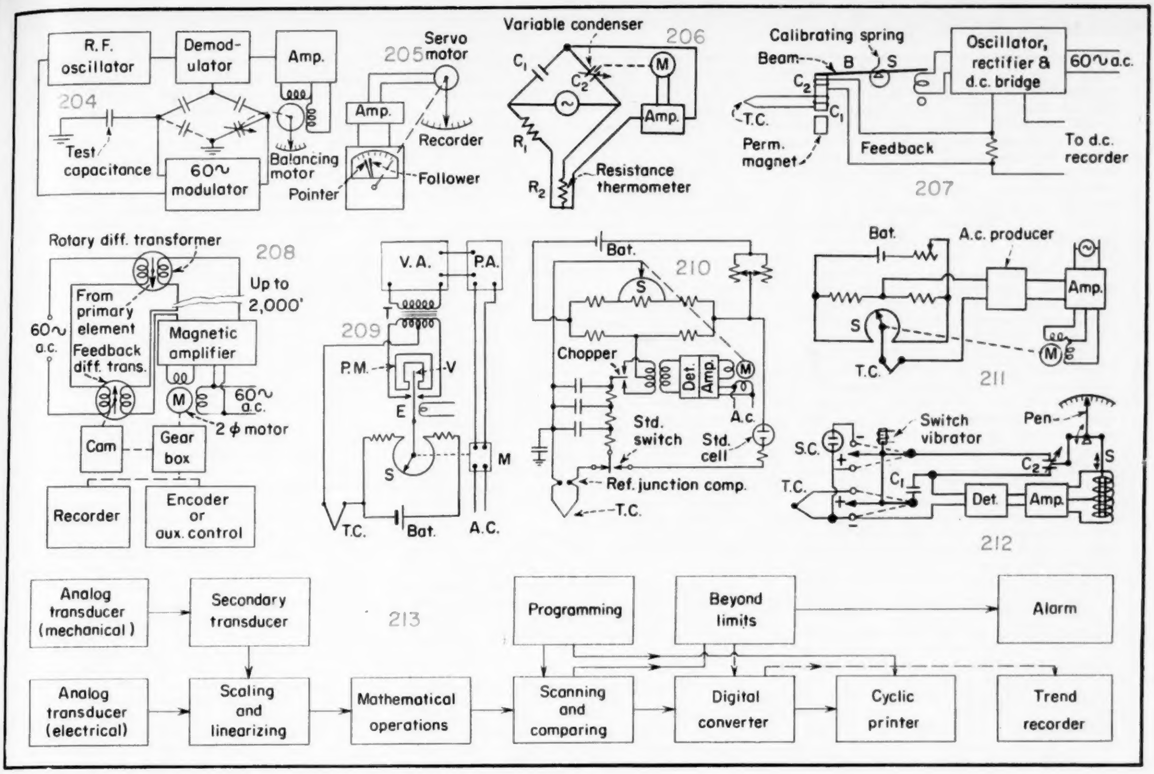
Most such electrical measurements are made by bridge circuits of one sort or another. These include wheatstone bridges, inductance and capacitance bridges, potentiometers and variations thereof. Some operate on d.c., some on a.c., and some may operate on either. Some use both, for example, measure the d.c. of a thermocouple, but convert the unbalance of the circuit into a.c. for amplification and operation of the balancing devices. A.c. bridges of various kinds have become more common in recent years.

Bridges of various sorts can in general be operated in two different ways; as deflection, or as null (balanced) circuits. Deflection bridges are relatively uncommon. The advantages of the null system in which the electrical values of the bridge are brought to a balanced condition, so that no current flows through the detecting device, are great enough in most cases to outweigh the greater cost of bridges with balancing features. Most balanced bridge circuits used in industrial instruments are of the automatic self-balancing type, although manual balancing is common in laboratory instruments, and in some industrial types such as electric conductive meters.

(a) Circuits

Direct voltage measurement by millivoltmeter. To a considerable extent millivoltmeters are used in measurement of temperature by thermocouples. Many of these instruments are indicators, but recorders are also made, some in which millivoltmeter movement operates pen directly by aid of a chopper bar and others in which recording mechanism follows millivoltmeter pointer without contact by means of an oscillating coil pickup system. In this method, pointer carries aluminum vane which moves between oscillator coils on a movable arm. If pointer attempts to move out of field of coils, output of an oscillating circuit is changed to drive a motor which causes coil carrying arm to move in same direction and at same speed as pointer. Position of arm controls recorder pen at corresponding position. Arm position can also operate control contacts easily, since plenty of power is available.

Voltage measurement by deflection potentiometer. In elementary potentiometer circuit of Fig. 195 it was noted that, with battery adjusted vs. standard cell, unknown voltages could be read by position of slider on slide wire which would give zero deflection of galvanometer. If slide wire is replaced by a series of tapped resistances, and galvanometer is calibrated as a millivoltmeter, then movable contact in unknown voltage circuit can be set at a point which will give only a little deflection to instrument. If both taps and millivoltmeter are calibrated in temperature (assuming a thermocouple is being



Figs. 204-213—Instruments for measuring values of process variables.

24. Measuring Methods (Cont.)

measured), then temperature is read as sum of that indicated by tap, and that indicated by millivoltmeter. Method is sometimes used where a low-cost indicator for one or a number of temperatures is desired and manual operation is suitable.

Voltage measurement by null-balance potentiometer. (See Fig. 11.) Most instruments requiring potential measurement use a null-type self-balancing circuit similar to Fig. 11. Null balance has advantage that, since no current is drawn in balanced condition, measurement is unaffected by resistance of unknown voltage circuit, or by changes in resistance. Long leads are no disadvantage. In Fig. 11 a switch (often operated automatically in self-balancing instruments) is provided for switching standard cell into circuit for standardizing battery by means of resistance R. Resistances 1, 2 and 3 are ordinarily of manganin for low temperature coefficient of resistance, and resistance 4 is of nickel for cold-junction compensation. (See Section 1d for method of bringing cold junction to instrument by compensating leads.) With thermocouple in circuit, instrument is balanced (manually or automatically—see below) by moving slide wire contact S until current through galvanometer G is zero.

Fig. 204—Capacitance bridge (Fielden). Used mainly for capacitance level measurements. Probe in tank serves as one capacity in a four capacity a.c. bridge. Second plate is tank wall. Variation in capacitance unbalances bridge, producing a 60-cycle modulated r.f. output which adds to signal from oscillator, is demodulated and amplified to drive balancing motor in direction to re-balance bridge by changing variable capacitor. Motor also positions recorder.

Fig. 205—Capacity follower (Fielden). For recording or controlling from millivoltmeters or other low-torque units, vane on pointer is followed without contact by a servo-operated follower. Capacitance bridge circuit similar to Fig. 204 detects capacitance between vanes, drives follower and recorder to maintain constant capacitance.

Capacitance potentiometer (Foxboro Co.). (See Fig. 212.) Capacities can be substituted for a pair of resistances in a potentiometer-type circuit, (see below).

Resistance bridge. (See Figs. 10, 203.) Widely used with resistance thermometers, conductivity meters, thermal conductivity gas analysis, etc. Applications where variations in lead resistance could upset response from sensitive element resistance use a three-wire lead as in Fig. 10. Lead wire resistance changes are put into both sides of bridge and so nearly cancel out. Variations of this circuit are sometimes used such as a double-slide-wire type which further improves canceling out of lead wire resistance changes. As in potentiometers, wheatstone bridges used in industrial instruments are commonly automatically self-balanced with some form of detecting mechanism G which will move slide wire contact S to point of zero current flow through G. Such bridges may use d.c. or a.c.

Inductance bridge. (See Figs. 225, 227.) Either two or four of the resistances in an a.c. wheatstone bridge can be replaced by inductances (or impedances). Fig. 225 shows a type which is self-balancing without usual self-balancing mechanism. Fig. 227 is a type used for precision determination of position of an instrument element.

Fig. 206—Capacitance bridge (Foxboro Co.). As noted above for potentiometers, two capacitances can be substituted for resistances in a wheatstone bridge circuit. Shown used with a resistance thermometer, capacities C_1 and C_2 replace a pair of resistances in Fig. 10. In a.c. bridge, any unbalance is amplified electronically and fed to reversible motor for altering the value of C_2 until current flow through detector circuit ceases. Temperature R_2 is indicated by position of balancing condenser.

(b) Balancing Methods

Fig. 207—Microsen system (Manning, Maxwell & Moore). This is an electronic-mechanical balancing system in which an electrical or mechanical input (measurement) is balanced against an accurately proportional d.c. output to an indicating or recording instrument. Basis of several variations of system is a balance beam which is upset by the primary measurement so as to affect an oscillating electronic circuit. Balance is restored to beam as circuit output reaches a value equivalent to initial upsetting force. Applied to measurement of a thermocouple potential, system consists of beam B (Fig. 207) with calibrating spring S and an armature at one end carrying coils C_1 and C_2. At other end, beam is in field of an oscillating coil O in an electronic oscillating circuit. Voltage output of thermocouple TC applied to coil C_1 causes rotation of B toward permanent magnet. But this changes electronic circuit output to recorder, also changing feedback through C_2 to restore balance. Instead, C_2 and electrical feedback may be omitted and direct mechanical feedback from recorder may be used to re-balance beam. Note that in this application system acts as a d.c. amplifier. Beam is comparable to a millivoltmeter in that circuit is not "nulled," and lead resistance has to be considered. Can operate up to 1,250 ft. from TC. On temperature, accuracy claim ½% of scale. Other applications on pressure, strain gages, pH and conductivity.

Fig. 208. Electrosyn system. (Norwood Controls). This method uses a magnetic amplifier, requires no vacuum tubes. Primary measurement rotates a rotary differential transformer connected to amplifier. A.c. voltage output is amplified, turns

Continued next page

2-phase motor geared to recorder, other auxiliaries such as encoders for telemetering or data logging and, through cam, turns a second differential transformer which feeds back an opposing a.c. voltage. Motor position which just balances feedback voltage against primary voltage represents current value of variable. Any change in primary measurement is followed by immediate re-balancing. Primary element and amplifier-recorder can be up to 2,000 ft. apart. System shown is used for mechanical inputs such as pressure and differential pressure. Temperature input from resistance thermometer is handled similarly except that a variable resistor is used for feedback balancing.

Non-galvanometer balancing systems. Most makers of self-balancing bridge and potentiometer instruments now supply continuous-balance instruments in which galvanometer formerly used is replaced by some method of electronic detection of unbalance. Characteristically, such instruments balance so rapidly as to be able to carry pen across entire chart scale in 2 to 20 sec.

Fig. 209—Brown Electronik (Minneapolis-Honneywell). Thermocouple output applied to potentiometer circuit if unbalanced is converted to a.c., direction of unbalance determining phase relation between generated alternating current and a.c. supply voltage so as to determine direction of correction applied by balancing motor M. If slide wire S is not balanced, current flow in thermocouple circuit is converted to alternating by transformer T through action of vibrating reed converter driven by a.c. at 60 cycles by coil E. Transformer output is amplified by voltage and power amplifiers and applied to balancing motor M. If in-phase, motor corrects for over-balance. If 180° out-of-phase, motor corrects for under-balance.

Fig. 210—Speedomax (Leeds & Northrup). Thermocouple output is applied to potentiometer circuit. If unbalanced, the excess is chopped to a 60-cycle a.c., amplified and used as power supply for one phase of a 2-phase motor; other phase is powered by plant supply. Motor drives balancing slidewire in proper direction to rebalance thermocouple output. At balance, supply of amplified current ceases. Similar balancing system is used for other bridge circuits.

Fig. 211—Dynamaster (Bristol Co.). Thermocouple output is applied to potentiometer. If not in balance, current in TC circuit is converted to a.c. by a synchronous switch. A.c. output is amplified and applied to balance motor to drive S in proper direction for restoring balance. This system with modifications can be used to balance circuits where the electrical quantity can be represented by voltage, current, capacitance or resistance. In resistance thermometers, for example, an a.c. bridge is used. Unbalance output, being a.c., can be amplified direct without synchronous switch.

Fig. 212—Dynalog (Foxboro Co.). This system is unusual in that it operates direct from std. cell without a separate battery and so needs no standardization. Vibrated switch alternately connects thermocouple and standard cell SC into capacitor bridge (contacts in upper position), then shorts capacitors through detector (contacts in lower position). SC charges C_2, TC charges C_1. If charges are unequal, detector output is amplified to drive solenoid bridge S and reposition C_3 and recorder pen. When balance is reached, short-circuit discharges become equal. Current drawn from SC is small enough that usual battery is not needed. Variations of capacitor bridge are used for other variables expressed as resistance, capacitance or inductance. Claimed accuracy, ¼%.

Instead of a standard cell some potentiometers use a regulated d.c. source, e.g., Bailey Meter's d.c. receiver for thermocouple and other d.c. pickups. This has a regulated electronic d.c. supply to serve as reference voltage without a standard cell, and no need for periodic standardization.

(c) Monitoring and Data Logging

Monitoring is the automatic supervision of one or more process variables. Generally implies use of alarms to show when variable is above or below set point by more than a predetermined tolerance. May also include, in addition to alarm function, digital logging of these variables at intervals by printing out numbers.

Continuous monitoring means a constant watch over all affected variables. Scan monitoring means sequential switching of instantaneous values of the variables and their comparison with standard values, with sounding or showing of alarm if out of limits and possible printing of digital value of variable, sometimes in color, or on special typewriter for trend recording.

In simplest form monitoring generally is continuous and uses high-low alarm contacts in each variable's own measuring instrument. In systems of more than a few points, scanning is likely to be used so that some equipment can be time-shared among all variables. This means using sampled data, requiring that each point be sampled often enough to catch important changes.

Fig. 213—Data logging. Scanning system, in addition to alarm function, may convert analog information acquired from each primary measuring system into digital information for automatic print-out on electric typewriters, for telemetering (i.e., Teletype code), or for feed to digital computers. Details are beyond scope of this review but main functions of a scan-alarm-logging system are indicated in Fig. 213.

Primary measuring device or transducer may be of any kind capable of producing an electrical signal such as a voltage, current, frequency or pulse rate. These include thermocouples, resistance thermometers, some velocity-type flow meters. If primary measurement results in an instrument position (e.g., pressure gages, head-type flow meters) position must be converted to an electrical quantity with a secondary transducer.

Individual electrical outputs are individually corrected for scale range and if necessary linearized to make response linear with variable. Certain measurements must then be operated on mathematically to convert to kind of quantity to be recorded. For instance, flow measured in differential pressure must be square-rooted. If total flow is to be recorded, flow rate must be integrated. A programmer then selects the channel to be recorded and feeds it to scanner where value is compared with a standard, e.g., a reference voltage, for that point. If outside limits, alarm system will be activated. Otherwise, quantity is fed to digital converter for normal recording.

In some systems an alarm will initiate operation of separate trend recorder for more frequent read-out. Or operator may plug in graphical recorder for continuous measurement of that variable.

Digital converters are of many types, both electronic and mechanical. In mechanical type (e.g., Fischer & Porter) shaft position of the self-balancing scanner potentiometer, time-shared by all variables, rotates a geared series of "units," "tens" and "hundreds" drums carrying "plateaus" and "valleys." These produce a pattern of two-way switch setups which in various combinations can code any quantity (represented as shaft position) in terms of numbers from 1 to 1,000, in any code such as decimal, binary, binary-decimal, for typing, telemetering or card punching.

25—Transmitters and Telemeters

General

The distinction between transmitters and measuring devices is not always clear. A measuring device is one that converts a primary indication into a position or into some form of energy that can easily be displayed as position on a scale to show the value of the primary variable. Some transmitters do the same thing, though others are primarily relays. If there is a real distinction it is that transmitters can display the value of the primary variable at a considerable distance from the primary element.

Transmitters for still longer distances are called telemeters. In some cases telemeters are designed to send over own wires, in other over phone wires or by microwave. Transmitters, however, may be pneumatic as well as electrical, but being shorter-distance senders, they use their own communication connections between sending and receiving devices.

A great many different methods are used for extending the distance measurements can be sent. In general these include hydraulic, pneumatic, electrical and electronic. If short-distance methods of getting away from friction-producing elements such as stuffing boxes are included, they also include mechanical (torque tubes) and magnetic methods.

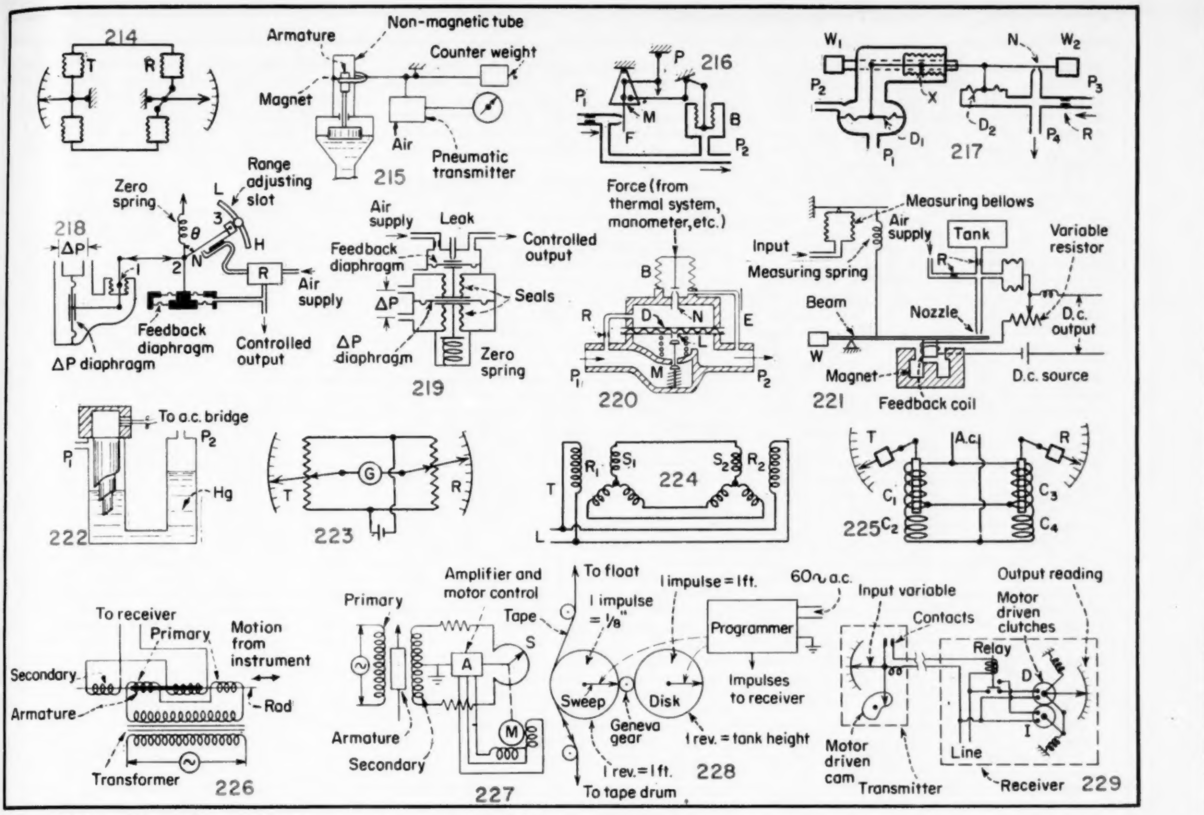
(a) Hydraulic and Magnetic

Fig. 214 — Hydraulic transmission (Liquidometer Corp.). Method used for transmitting liquid level measurements from a tank float employs two transmitting and two receiving bellows, connected by two lines, with system filled solid with liquid. Purpose of double-bellows system is to compensate for ambient temperature changes. Expansion or contraction due to temperature affects each bellows system equally, being cancelled out by link between receiving bellows. However, movement of pointer at transmitting end (representing position of float or other measurement to be transmitted) expands one bellows, contracts other, so moves receiving pointer an equal amount.

Fig. 215 — Magnetic follower. Method often used to transfer motion inside a sealed system to outside without loss of accuracy due to friction in a stuffing box. For example, used in level gages and controllers, flow manometers and rotameters. A level gage made by Magnetrol, Inc. uses magnetic follower to operate level control switches. Yarnall & Waring makes a level gage (Fig. 84) which transmits position of a manometer by means of a magnet which turns a spiral follower attached directly to the pointer. In Fig. 215 a float in a level gage or manometer operates armature in a non-magnetic tube to position a transmitter.

(b) Pneumatic

General: Pneumatic transmitters are coming into extensive use, especially since development of the pneumatic force-balance type of measuring device. Such transmitters are used for temperature, pressure, differential pressure from flow, level and density measurements, weight, force and position. With the development of close-coupled control systems with remote set and indication at the panel board, they are being used to transmit to a controller close to point of measurement, and to an indicating or recording instrument at a remote panel board. Similar transmitters, balanced against pressure of a spring, are being used to produce loading pressure for remote setting of controllers in such installations. This method takes the re-



Figs. 214-229—Transmitters and telemeters for process variable measurements.

25—Transmitters and Telemeters (Cont.)

corder out of the control loop, puts controller and point of measurement close together, and so cuts instrument lags to minimum.

Fig. 216—Positioning non-balance transmitter. Diagram illustrates principle, shows no particular type. Measurement pointer P positions a flapper F before a nozzle, raising or lowering pressure P_2 by changing leak at nozzle. Bellows B moves movable fulcrum M in direction to oppose change, acts as a feedback so that each output pressure P_2 demands an exact position of F. Thus P_2 is proportional to position of pointer P. P_2 can be transmitted. For use over considerate distances where a considerable lag in transmission is to be avoided, P_2 is fed to a relay air valve to increase flow during time that P_2 is changing.

Fig. 217 — Force-balance transmitter, beam type (Republic Flow Meters Co., others). Force from any sort of measurement (shown here as that of a differential pressure diaphragm) is applied to a weight-balanced beam pivoted at point X. In this application X is inside a bellows used as a frictionless seal for the differential pressure system. Beam obstructs flow of air from nozzle N which is supplied with air at pressure P_3 through restriction R. Assuming P_1 increases, beam will tilt to raise nozzle pressure P_4, but this increases pressure on diaphragm D_2 which restores beam to substantially its original position. Hence P_4 is balanced vs. the differential pressure, either exactly, or in some multiple depending on the relative lever arms. P_4 is transmitted. A similar beam type can be used for ratioing as in Fig. 254.

Fig. 218 — Force-balance transmitter, null balance-vector type (Republic Flow Meters Co.). Newer type than Fig. 217, in which vectorial forces are combined by linkages, with range adjustment through changing angle theta by sliding pivot 3 in a calibrated slot. Differential pressure delta P is measured by a diaphragm, with motion taken out by lever pivoting at 1, through seal bellows. Link pivoted at 2 raises or lowers link pivoted at 3 when delta P changes, amount of this movement varying with angle theta. If differential increases, link 2-3 lifts, lowering air pressure in nozzle N. Reverse air relay R then raises output pressure, also raising pressure on feedback diaphragm and moving pivot 2 downward to restore balance. Output pressure is directly proportional to initial differential pressure.

Fig. 219 — Force-balance transmitter, stack type (Taylor Inst. Cos.). Where Figs. 217 and 218 interposed beams or linkages between measured and output pressures, permitting lever arm change to change proportionality, several makers supply a force-balance instrument in which the balance is direct, on opposite sides of a diaphragm or bellows. Figs. 219 and 220 show this principle. In Fig. 219 the resultant of differential pressure on both sides of the lower diaphragm (or a single pressure on the lower side only) is opposed by the controlled air output pressure so as to balance. Air supply enters through a restriction and flows through the chamber above the upper diaphragm. If upward pressure from the delta P diaphragm increases, air loss through the leak decreases, pressure rises in the upper chamber and outlet, meanwhile balancing the increased delta P. If delta P falls, leakage increases, top chamber and transmitted pressure fall. Transmitted pressure is directly proportional to delta P.

Fig. 220 — Air-relay force-balance stack-type transmitter (Moore Products Co.). Similar in principle to Fig. 219 except that it incorporates an air relay to give rapid changes in output pressure. Air at pressure P_1 enters transmitter, is applied through restriction R to nozzle N and top of diaphragm D. Any force such as that from a liquid-filled thermometer system is applied to top of bellows B, restricting delivery from nozzle N. Increased back-pressure over diaphragm D closes leak L through porous-center diaphragm D, opens main valve M to increase pressure P_2. This works through equalizing line E to raise pressure in B, thus restoring initial nozzle opening (almost). Now output pressure balances force. Assuming force then decreases, nozzle delivery increases, pressure over D falls, and leak L bleeds air to lower P_2 until P_2 again equals force. Response of instrument depends on force of calibrating spring under main diaphragm D. Main valve M acts as relay for quick changes.

(c) Electric and Electronic

General: Several transmitting and telemetering methods are in use which can be classed as electrical rather than electronic, in that they do not require vacuum tubes or transistors for amplification.

One method now being widely used appears in several guises under different names, although the principles involved are generally similar. Among these are the inductance bridge, the impedance bridge and the differential transformer. All are a.c. bridge circuits in which the degree of coupling between inductances is varied by altering the amount of iron core within a coil.

Fig. 221—Electropneumatic transmitter (Fielden). Converts motion from a pressure or other transducer to directly proportional d.c. current of 3-15 milliamps. Balance beam is lifted by motion it is to measure. This closes a nozzle, allowing

Continued next page

air pressure to rise in a pneumatic-to-d.c. transducer consisting of some form of variable resistor. Increased d.c. output flows through feedback coil which magnetically restores balance of beam, making d.c. current proportional to initial force applied through measuring bellows.

Fig. 222 — Resistance manometer (Republic Flow Meters Co.). This is a unique device for transmitting the height of mercury in a flow manometer. A spiral of rods in the manometer, arranged to compensate for the square-root relation in flow (See Sections 2e and 5) is connected to resistances so that as mercury shorts out more or less of the rods, total remaining resistance is proportional to the flow rate. Flow rate indication and recording are obtained by passing a.c. from manometer through a bridge circuit which measures the conductance by means of a core drawn into a coil an amount depending on the resistance of the manometer. Integration of flow is by means of an instrument similar to a watt-hour meter.

Fig. 223 — Wheatstone bridge transmitter. Null-balance wheatstone bridge can be used to transmit indications by contact on slide wire T which is positioned by measurement to be transmitted. Unbalance indicated by galvanometer G then operates to move contact on slide wire R to balance position, which then reproduces position of T. Alternatively, transmitting resistance T in Fig. 223 may be varied by temperature (resistance thermometer) or by a force (strain gage), and the resistance change mirrored at R. For example, strain gages are used by Brooks to transmit rotameter readings.

Fig. 224 — Self-synchronous motors. Motors with three-phase stators S_1 and S_2 and two-phase rotors are connected to same line. Rotors remain stationary unless turned by an external force. If primary rotor R_1 is turned, R_2 will follow closely with lag of 1 to 3°. Selsyns may be geared together to transmit both feet and inches in remote level indication (Shand & Jurs). "Inches" transmitter turns 12 times for each turn of "feet" transmitter, with corresponding indications of two receiver selsyns.

Fig. 225—Inductance bridge. Used for transmitting indications from inside sealed instruments, such as flow meter manometers, rotameters, etc. Transmitter and receiver coils are connected as shown by three wires in a bridge arrangement and supplied with a.c. Transmitter soft iron armature is positioned vertically by measurement to be transmitted. Receiving armature positions itself similarly. This device is self-balancing without usual balancing devices. Any unbalance due to armatures being unequally placed in coil pairs results in current flow through center lead which brings about re-balance by altering flux distribution until balance is reached.

Fig. 226 — Differential transformer (Automatic Timing & Controls, Inc., others). This device is an a.c. motion transducer which can be designed to produce an electrical output over a full range with any desired range of motion of the armature. Type shown allows long armature travel; other types down to fractions of an inch. Transformers have one or two primaries and two secondaries, generally connected to "buck" each other. A.c. is applied to primary. A.c. produced in secondaries depends on position of armature and amount of coupling so produced. Such devices provide accuracies of ½ to 1% of full range and can be used to transmit forces, pressures, differential pressures, weights, and the like. Can transmit up to 5,000 ft. Type illustrated has linear motion of core. Rotary differential transformers are used in a number of instruments, e.g., Inertial Inst. mass meter (Fig. 77) and Electrosyn transmitter (Norwood Controls, Fig. 208). Several instruments use what is in effect a differential-transformer bridge, e.g., Electrosyn transmitter and a remote level transmitter supplied by Yarnall-Waring Co.

Fig. 227 — Impedance bridge (Bailey Meter Co., others). Transformer with single primary supplied with a.c. and double secondary has movable armature I positioned by measurement to be transmitted. Secondaries S_1 and S_2 are in a bridge circuit. Unbalance due to I not being centered is amplified by A and transmitted to a balancing motor M which repositions slide wire to balance. Slide wire position is a measure of position of I in transformer.

D.c. converter (Bailey Meter Co.). Variation of Fig. 227 eliminates amplifier and slide wire, uses two diodes to convert output of secondaries to d.c. in a d.c. bridge. Unbalance resulting from armature movement is put out as d.c. voltage proportional to armature position.

D.c. transmitter (Manning, Maxwell & Moore). Microsen balance measuring device of Fig. 207 is used to transmit measurements which are initially voltages or forces, converting these to d.c. which can be transmitted considerable distances. Receiver employs a second Microsen with feedback to make pointer position proportional to signal. Signal positions rotary solenoid from output of receiving Microsen, with mechanical link from solenoid to balance-beam restoring spring. Solenoid positions indicating pointer. Mechanically loaded Microsen beam can be used for remote set-point adjustment of electronic controllers.

(d) Impulse and Timed Signal

General: Impulse and timed-signal methods of telemetering have advantage of giving accuracy independent of supply voltage variations. There are several methods: (1) sending a number of electrical impulses proportional to the value of the variable, and counting pulses at the receiving end; (2) sending a signal whose frequency is proportional to the variable; (3) sending a single pulse whose duration, as a fraction of a fixed time interval is the same as the ratio of the variable to its maximum value; and (4) sending a pattern of pulses in code, such as decimal or binary-decimal, corresponding to the digital value of the variable.

Fig. 228—Pulsed-signal level telemeter (Shand & Jurs). One of several pulse methods of transmitting continuously varying variables such as liquid level and tank temperature is shown in Fig. 228. Transmitter cycle has three parts. Remote operator signals any individual tank for level and/or temperature. Selected transmitter first sends pulse group identifying itself. Then sends level, first "feet," then "inches" by eighths. "Inches" disk driven by perforated steel float tape, makes one revolution for each foot of float movement. Then advances "feet" disk one increment through Geneva gear. When instrument is asked to transmit, a motor-operated sweep scans each disk for its position, first the "feet" and then the "inches" disk, sending for each a number of pulses corresponding to the disk position. Receiver dials are ratchet-operated by incoming pulses to count exactly.

Fig. 229 — Timed-signal telemeter (Builders-Providence). Rotating cam lifts a follower for a period during each cycle proportional to measured value. This closes switch and sends a signal over a two-wire line to receiver. Duration of signal during each cycle is therefore proportional to measured variable. Receiver has two clutches, one "increase," one "decrease." The first runs while current is on, the second during part of cycle when current is off. Transmitted value is the difference. Pen moves only when difference changes. Works over long distances at high accuracy.

26—Controllers

General

Controllers are of many types although most of them can be classified according to the type of control which they are able to supply. Apart from the control type, there are two general methods of controller operation; self-operating and pilot-operating. Self-operating controllers use energy taken either directly or indirectly from the controlled system to operate a valve or other controlled device which regulates the supply of the control medium Pilot-operated controllers control a supply of energy in the form of a fluid under pressure (usually air), or electricity. The controlled pilot fluid then makes the necessary adjustments to the controlled device. An intermediate type of controller uses the energy of the control medium to amplify its responses and so control the control medium.

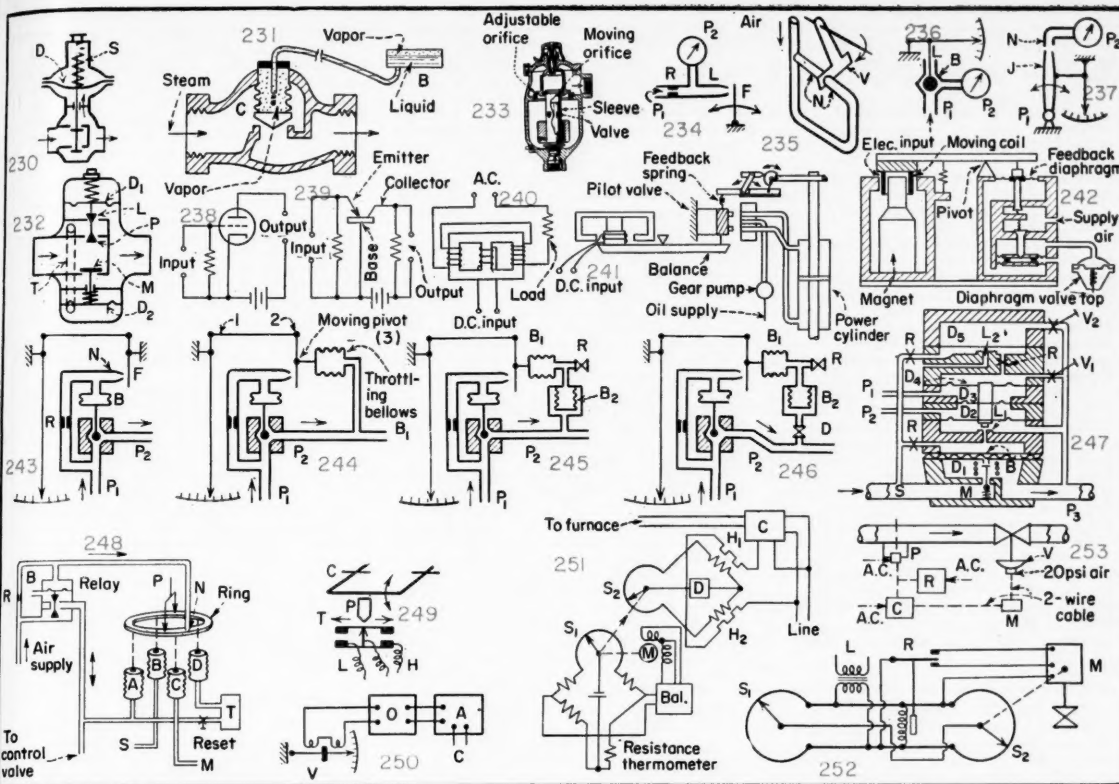
Modes of control. Most industrial control problems involve as the end result of the control action the regulation of flow of a control medium such as steam or other heating medium, or electricity, or a process fluid. This means control of flow. The flow can be controlled in an off-and-on manner—either between high and low limits or completely off and on; or it can be controlled in a throttling manner—at a rate intended to balance the instantaneous demand. Since the throttling type of control seeks to proportion the flow of control medium to the demand, it is known as proportioning or proportional.

Proportional control is the type most used in industrial work, but for processes other than the simplest, additional control responses beyond simple proportional action are often added. The first of these is the reset response. In any simple proportional controller there is only one rate of demand at which the controller will control exactly at the desired control point. If there are large or permanent changes in demand this means usually that the controller must be reset by hand. To avoid this many controllers have the reset feature supplied automatically. A comparison of Figs. 244 and 245 shows one way in which this can be accomplished. In a proportional controller without reset the controller output (e.g., pressure on the control valve) is related directly to values of the measured variable. This means that with load changes, different controller outputs will be needed to maintain the same control point. Automatic reset supplies this flexible feature by adding a second controller response which changes the controller output at a rate proportional to the amount of deviation.

There are still other possible responses that can be added to a proportional controller. The most common one, in addition to reset, is called the derivative response. It changes controller output at a rate in proportion to the rate of change of the deviation. Its effect is to give the process an extra quantity of control medium if a sudden increase in demand takes place, then to cease its effect entirely as soon as the deviation has been arrested. One way to add this response is shown in Fig. 246.

(a) Self-Operated

Fig. 230—Self-operating pressure regulator. This controller adjusts its valve opening by the relation between the downstream pressure applied to bottom of diaphragm D and the pressure of a spring S.



Figs. 230-253—Automatic controllers and final control elements for process variables.

26—Controllers (Cont.)

If downstream pressure falls, valve opens wider, and vice versa. Self-operating temperature regulators are quite similar. Pressure of a filled (usually vapor pressure) thermometer system is applied to a bellows which opens or closes the valve. If temperature rises, valve closes to decrease flow of heating medium (or valve opens to increase the flow of cooling medium). Since some margin for operation is required, these devices cannot give as close control as pilot-operated controllers. They are used for less critical control problems such as water heating, dry rooms, jacket water cooling, etc.

Fig. 231—**Hot chamber regulator** (Fulton Sylphon). This device represents the class of intermediate controllers in which energy from the control medium is used to increase sensitivity of control. Hot chamber C within the steam valve (on supply side) receives vaporizing liquid from temperature bulb B if controlled temperature rises. This liquid vaporizes in C, provides energy to close valve against steam flow. Decrease in temperature at B allows vapor to condense, drawing vapor back from C and increasing valve opening. Thus valve throttles at opening determined by demand.

Fig. 232 — Self-pilot pressure regulator. Except for small sizes, pressure regulating valves usually have a built-in pilot device operating from the pressure of the fluid being regulated. Valve in Fig. 232 is typical. Where self-operating type (Fig. 230) gains control only from downstream side, self-piloted types use fluid bled from high pressure to low pressure side to act as a source of pilot energy. If downstream pressure falls, diaphragm D_1 opens pilot valve P, allowing upstream pressure to force D_2 upward and increase opening of main valve M. When upstream pressure rises, D_1 closes P, opens L to low pressure side and allows D_2 to fall and M opening to decrease.

Fig. 233—Self-operating flow regulator (W. A. Kates Co.). Constant pressure drop maintained across adjustable and moving orifices. Adjustable orifice set manually to desired flow rate. Compensating sleeve valve, located in the inlet flow, is connected to the moving orifice which is between the intermediate and outlet chambers. Pressure difference between chambers operates moving orifice. Loading weight attached to sleeve determines the balance pressure difference. Increase in inlet pressure causes rise in intermediate pressure. Sleeve and disk move upward, thus restricting inlet ports until intermediate pressure returns to original value above outlet pressure. Increase in back pressure causes reverse action to take place. Pressure differential within unit adjusts valve position proportional to desired flow.

(b) Pilots and Relays

Figs. 234, 235, 236, 237 — Non-relay pilots. Pneumatic and hydraulic controls use various forms of pilot device to produce an output pressure which varies in some suitable manner with a primary measurement. Most of them also incorporate a relay to increase flow of pilot medium while changes are taking place. For simplicity relays are omitted in these figures. Fig. 234 represents the common flapper or baffle type in which the measurement is translated into position of the flapper before the nozzle. If the flapper approaches, pressure of air P_2 rises, leakage at L decreases. The free-vane flapper, Fig. 225 (Bristol), was developed to overcome the disadvantage of the ordinary flapper that nozzle pressure does react on the flapper and hence on the measuring system. Vane V moves between opposed nozzles N so that the thrusts of the nozzles on the valve are cancelled out. Fig. 236 shows the common ball-type pilot in which position of the ball B, controlled by the primary measurement, determines the pressure P_2 by varying the inlet oppositely to the leak L. Fig. 237 shows the unique hydraulic jet pilot used by Askania Regulator Co. A swinging jet pipe positioned by the primary measurement delivers more or less of its impact pressure to the pressure receiving device, depending on its position. This device ordinarily moves a piston by swinging back and forth over a partition separating pipes leading to the two ends of the piston.

Figs. 238, 239, 240—Electrical means of amplifying minute electric signals to give suitable outputs for recording, control or telemetering. An elementary vacuum tube circuit, Fig. 238, permits amplification of a feeble a.c. voltage, usually 1 v. or more, and produces an output signal many times stronger. Amplification of signals in the millivolt range with minute power requirements takes place with a transistor (PNP type), Fig. 239. The transistor in suitably arranged circuits can produce power gains in the order of 10,000 times. The principal advantage is that the transistor does not require the power supply necessary for vacuum tube operation. The transistor responds at once with no lag for heating of cathodes and does not need to be kept in standby operation for response to input signals. The magnetic amplifier, Fig. 240, has two windings mounted on an iron core. The signal or control winding carries a d.c. input, the load winding a.c. The impedance of the load winding varies with the degree of magnetic saturation of the iron core. As long as the core is not saturated, the impedance of the load winding is high, hence little current flows in load. When the magnetic flux in the core is increased to saturation by the d.c. signal, the impedance of the load winding drops sharply and load current increases

Continued on next page

in proportion. Load determines maximum current The magnetic amplifier controls load current between the limits of 3 to 97% of full value.

Conversion of remote electrical signals to another form of energy large enough to position valve stems or produce shaft displacements requires forms of relays. The relay then operates a pneumatic or hydraulic system to effect necessary motion.

Fig. 241—Electrohydraulic relay (Manning, Maxwell & Moore, Inc.). Input current causes unbalance of Microsen beam (see Fig. 207) and operates pilot valve. Oil supplied by gear pump is directed to power cylinder, thus producing movement of piston proportional to signal. Feedback spring, which is connected to output stem through a series of links, expands or contracts in response to stem movement and applies restoring force to the beam. Pilot valve ports are then closed and output piston is at required position.

Fig. 242 — Electropneumatic relay (Swartout Co.). Moving coil carrying the input signal is positioned in a magnetic field. The lever arm moves in response to this force, A signal for increased output pressure forces the pilot valve stem down, increasing supply air to booster relay diaphragm. The booster valve stem then rises and admits more air to control valve. When output pressure balances to new condition, booster valve closes on relay diaphragm, and feedback diaphragm moves away from pilot valve stem. System is then in balance at required pressure.

(c) Pneumatic Controllers

Figs. 243, 244, 245, 246 — Pneumatic controller development. This sequence shows four steps in development of a controller from a relay-pilot-operated on-off controller, through a simple proportional type, to proportional plus reset and proportional plus reset plus derivative. In Fig. 243 the nozzle-flapper combination of Fig. 234 is combined with the ball pilot of Fig. 236, the later positioned by a bellows B to act as a relay. Air pressure P_1 flows both to the ball valve and through restriction R to nozzle N. Flapper F is positioned by the measured variable. Changes in position of F through the relay action of B and the ball valve produce such great changes in P_2 that such an arrangement cannot throttle easily and so is used for on-off control. To make this controller give proportional action it is necessary to add feedback as in throttling bellows B_1 in Fig. 244. When a change occurs in the primary measurement and flapper and relay change P_2 as a consequence, B_1 acts to move the flapper's moving pivot away from the nozzle. Each position of the measurement gives a definite flapper position and definite output pressure P_2. Note that in arrangement shown, moving flapper towards nozzle decreases P_2. To change control point of controller, some way of changing length of link figure 1 is used. To change proportional band (throttling range), distance from pivot 2 to pivot 3 is changed.

Reset response. To obtain reset action in the controller of Fig. 244, an additional bellows B_2 and adjustable leak R are added as in Fig. 245. In Fig. 245 controller has droop, every value of load giving a slightly different control point. To obviate this, a "floating" component is added to the response by allowing the flapper pivot to move temporarily, as in proportional action, but after a time returning the pivot to its original position. P_2 is now applied through a new bellows B_2 to B_1, giving initial response as in Fig. 244. However, after a time determined by setting of leak R, pressure in B_1 returns to atmospheric and flapper pivot returns to initial point. Leak rate is "reset time."

Derivative response, Fig. 246. Adding derivative or rate response to controller of Fig. 245 consists merely in adding an adjustable restriction between output line P_2 and reset bellows B_2, thus slowing down effect of proportional action with a change, and giving initial rapid change in P_2 almost as in Fig. 243. After a time this effect wears off as P_2 reaches bellows B_2. Time for equalization is "derivative time." Most actual pneumatic controllers work much as these simplified sketches show, with proper adjustments added. Many actual variations in design detail.

Fig 247 — Stack type force-balance controller (Moore Products Co.). Controller shown has pneumatic set-point and variable measurement, proportional and reset action, with relay valve (See Fig. 220). Set pressure P_1 is balanced against measured variable pressure P_2 by means of diaphragms D_2 and D_4. Restriction V_1 controls proportional band, and V_2, reset time. Pressure relations on diaphragms D_2, D_3 and D_4 control leak rate through nozzle L_1 and hence pressure over D_1. In turn, this controls output P_3 by either admitting air at M or exhausting at bleed B through porous center of D_1. Pressure P_3 under D_2 opposes any change. D_5 controls L_2, thus controlling pressure over D_4 in relation to flow rates through V_1 and R.

Fig 248 — Beam type force-balance controller (Foxboro Co.). This controller uses a beam in form of circular annulus, pivoted above by rotatable pivot arm P and pushed upward against pivot arm P by four bellows, A, B, C and D. These are in contact with annulus. With pivot points over bellows A and D, proportional band is zero. With pivot points over bellows B and C, proportional band in infinite. At intermediate locations, practical proportional band percentages are obtained. Bellows B contains set pressure and bellows C, measurement pressure. Bellows A is throttling bellows, and bellows D, reset bellows. Relations of these four pressures and the pivot points determine leak at nozzle N. Supply air flows through restriction R to nozzle N, also to relay valve. Nozzle pressure determines valve position in relay, and hence relation of bleed B and pressure delivered to control valve and bellows A. Any change in set vs. measurement pressures B and C causes beam to tilt depending on proportional band setting. Bellows A opposes change while D initially puts in no correction of its own, but gradually opposes A (aids change) as reset time runs out.

(d) Electric Controllers

Fig. 249 — Electric contact control, high-low type. One of several ways in which contacts can be closed mechanically in electric measuring instruments having a pointer. Pointer P swings freely except at intervals when a chopper bar C descends, pushing it against a contact table T. Table tilts if pointer is high or low, making corresponding contact with force enough to complete necessary circuit through relay, or direct.

Photoelectric cut-off. Various types of control can be applied by means of photocell and light beam, for example in scales where a relay is tripped at set weight.

Fig. 250 — Oscillating coil control pickup (Wheelco Inst. Div.) Instrument pointer carries a vane which swings freely between coils in an oscillating electronic circuit. Coils are on control-point set arm. If vane V leaves coils, circuit oscillation changes, operates a relay to increase or decrease, turn on or shut off flow of control medium. In two-position control, vane movement of 0.006 in. will operate relay.

Fig. 251 — Electric heat control, duration-adjusting type (Leeds & Northrup Co.). Controls % of time during a short cycle in which electric heat will be on, to give proportional control without current flow adjustment. Measuring circuit sets slide wire S_1 which in turn sets S_2 in control bridge. Relay detector detects unbalance calling for heat and closes circuit to furnace, at the same time providing heat to a slow heater H_1 and a fast heater H_2 which provide heat to two bridge-circuit resistances R. Effect of heat in resistances is to rebalance bridge and cut off contactor C after time proportional to demand. Second slower heater adds response also for time that temperature has been off control point so as to reduce time to return temperature to desired value. Condensers and resistances in output of second bridge supply reset, derivative and feedback. Combined outputs of two bridges is fed to amplifier for control of final element.

Fig. 252 — Proportional electric control. Various ways are used for obtaining proportional control electrically with bridge circuits. A simple circuit with proportional action only uses a bridge in which the measured value sets slide wire S_1. Bridge unbalance is detected by relay R which operates motor valve M in proper direction, at the same time changing slide wire S_2 until balance is reached, when the valve motor stops.

Fig. 253 — Electronic-pneumatic control (Swartwout Co.). Primary sensitive element is a resistance thermometer or some element such as a pressure gage, manometer or other device which provides a potential proportional to measured value, either direct, or with a differential transformer used as a transducer. Measurement is transmitted as a.c. over two wires to controller, and also to recorder. Control impulse, which is d.c., goes over two wires to manual control station and to a power relay at final control element which controls air supply to pneumatic control valve. System eliminates instrument lags, gives claimed accuracy of ½%.

(e) Ratio Control

Fig. 254 — Ratio totallizer (Hagan Corp.). Balance beam device operated by combination of pressures or other forces gives a combined output P_4. Fulcrum F can be moved to change lever arms. Can be used to add, subtract, multiply or average pressures, or can be connected up as a pneumatic-set, pneumatic-measure controller of proportional, or proportional plus reset type. Combination of two gives proportional plus reset plus derivative. Balance of pressures P_1, P_2 and P_3 determines output pressure P_4 which thus serves as a force-balance transmitter.

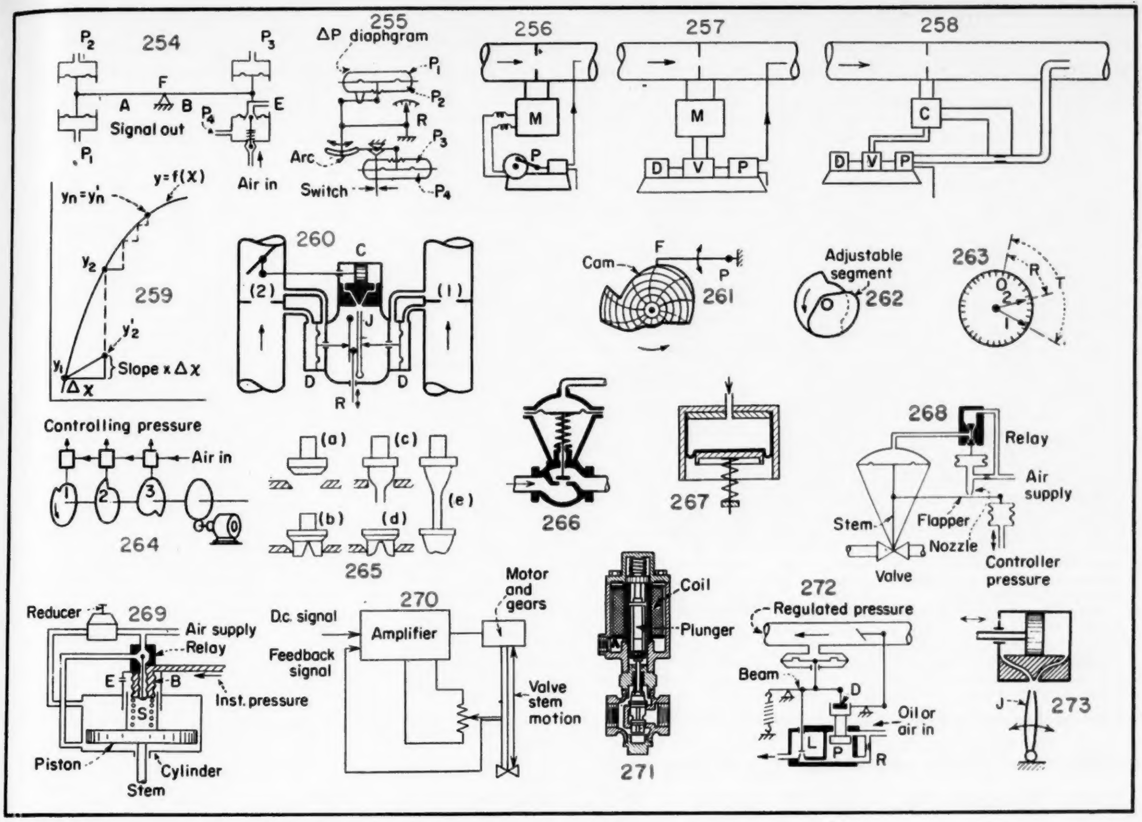
Fig. 255 — Ratio control mechanism (Hays Corp.). Similar in general effect to Fig. 260, but differs in detail. Different pressure or pressure diaphragms are ratioed by linkage having setting pointer, and link moving in a curved slot. If ratio is not correct, contactor attached to captive stream diaphragm makes high or low contacts to control damper motor.

Fig. 256 — Proportioning pump paced by meter. Contact-making meter gives impulse to proportioning pump each time a certain flow quantity passes through main line 1. Then pump injects a fixed quantity of treating solution into 1 through line 2. Many variations of this principal.

Fig. 257 — Continuous-flow proportioning. Meter in main line drives a differential gear V, or adjusts a variable speed transmission V interposed between driver D and pump P. Methods such as this can give infinite range of ratios, with accuracies in the order of 0.01%

Fig. 258 — Continuous flow proportioning with feedback control of secondary flow. Controller C maintains desired ratio between primary and secondary flow. Controller C in response to differential signal from main stream paces variable speed transmission V located between driver D and pump P. Differential tap in secondary stream continuously senses secondary flow and transmits signal to controller. Controller, comparing primary and secondary flow to desired ratio, makes corresponding adjustment in pump speed.

Fig. 259 — Optimizing controller (Quarie Controllers). Maintain operation of a process at a slope on the process curve. Control is maintained at a predetermined rate of change of an uncontrolled variable with respect to a controlled variable. Basically the controller



Figs. 254-273—Automatic controllers, timing device, and final control elements for process variables.

26—Controllers (Cont.)

makes a change Δx in the process $y=f(x)$; predicts what the result y_2 of the change will be. After the process has stablized y'_2 from the change, the controller compares the expected result y_2 with the actual results y'_2. Further control action is based on the difference and direction between the actual and predicted values. As the desired slope is approached at y_n, the size of the change increments Δx decrease to zero, thus giving stability to the control action.

Fig. 260—Flow (pressure) ratio control (Askania Regulator Co.). Ratio of pressures or differential pressures in pipes 1 and 2 sets position of jet pipe J (See Fig. 273). Effect of two pressures may be adjusted by pivot point determined by ratio adjuster R. Jet pipe positions piston in power cylinder C to adjust damper in captive stream 2 for desired ratio.

Cascade control, in closed-loop systems, involves adjustment of the set point of one controller in response to a signal from another controller. Each controller measures separate but related variables. Cascade systems can be used to maintain a desired relationship between two variables (for an example, see Fig. 258); limit accurately a secondary variable; reduce load changes, nonlinearities and discontinuities, near their source; and improve the control circuit to reduce time lag.

(f) Time Relations

General: Many operations are conducted as variable against time. In other cases timers are used to start and stop processes without time-sequenced adjustment of control point. Fig. 261 shows a typical cut cam for use on a round-chart recorder-controller equipped with a control point follower. Cam is printed with chart for ease in cutting to desired time-variable relation. In some cases where processes may change from time to time, it is possible to use an adjustable cam similar to the type shown in Fig. 262. Interval timers usually are provided with a time dial and one or more hands which move counter-clockwise. Fig. 263 shows one type. Hand 1 is set to total time T. Hand 2 moves to position 1 and starts process. When hand 2 reaches 0, process stops. At any intervening time R, hand 2 shows remaining time. In processes involving many time-sequenced parts program controllers as in Fig. 264 are used. Here a motor drives a shaft carrying cams 1, 2 and 3. Such cams can be used to vary control points of pneumatic-set controllers as well as to start or stop various portions of the process at predetermined times. Cams can also be used to operate electric switches.

27—Final Control Elements

General

Most commonly, the final control element in an industrial control system is a valve since a fluid is likely to be the control medium. However, it may be a positioning device for other purposes, a switch, rheostat, variable-speed drive, damper, etc. Since valves are the most important of these elements, this section will be confined to them, although it should be understood that most of the operators described can be applied to other final elements than valves.

Valve characteristics. Control valves are of many designs but in general their characteristics may be described as bevelled disk, V-port, equal-percentage plug, equal-percenage V-port, and linear plug. For throttling service, control valves are usually double-seated so as to be substantially balanced against line pressure. Valves may open on increase in pressure of the control medium, or they may close with medium pressure increase. In most control applications today, the so-called characterized valves are used. Fig. 265 shows the main inner valve types: *a* is a bevelled disk, *b* a V-port, *c* and *d* equal-percentage plug and V-port inner valves, and *e* a linear plug. Sketch *e* shows both parts of the double plug as used in balanced valves.

(a) Pneumatic Operators

Valve design. Many control valves incorporate special features such as finned bonnets for cooling of the stuffing box on service above about 400F.; special methods of reducing stuffing box friction or possible leakage, such as bellows type seals, grease seals and special packing; extension bonnets to prevent freezing; and special types of closure device, such as pinch valves, flexible diaphragm valves (Saunders type), and dampers, etc.

Fig. 266—Diaphragm-top valve. Commonest type of control valve operator is

Continued next page

27—Final Control Elements (Cont.)

the diaphragm top, making the valve a "diaphragm motor valve" (DMV). Diaphragm tops are of two types: air-to-open and air-to-close. In either case the motion of the diaphragm is opposed by a calibrated spring so as to make valve stem position proportional to pressure. An interesting modification in diaphragm valve tops is the Isoforce actuator (Foster Eng. Co.) which combines some of the features of the conventional top (Fig. 266) with the piston top (Fig. 269). This top, Fig. 267, uses a diaphragm over a piston. The diaphragm seals the piston frictionlessly, permitting full stroke, and use of higher pressures.

Fig. 268—Valve positioners. Owing to friction in stuffing box of a control valve, it is difficult to position stem accurately in proportion to controller output pressure. Also, there will be hysteresis. A positioner can be used to make stem position accurately responsive to pressure. Positioners vary in detail but in general are similar in principle to Fig. 268 in which controlled output pressure is applied to one end of a beam supported at other end by valve stem. Beam acts as a flapper in conjunction with a nozzle and relay air valve. In air-to-close valve shown, increase in pressure lifts beam, raises nozzle pressure and lowers valve stem (feedback) to bring definite stem position.

Fig. 269—Piston-top valve (Annin Co.). Longer stem travel, together with more power for large valves can be secured with a piston-type valve motor. Design shown has built-in positioner giving stem position directly proportional to controller output pressure. Piston loaded on top with constant pressure in L from reducer. Instrument pressure inside double bellows B is balanced against calibrating spring S, positioning pilot valve which controls admission of air either under piston, or to exhaust E. Position accurate to 0.001 in.

(b) Electric and Hydraulic Operators

Combination valve operators. With the coming of electronic control a need has developed for setting the opening of the final control element from a small electric signal. Although there is some development in all-electric valves for this purpose, most of the effort thus far has been in combination operators which receive an electric signal and produce a controlled output of air or a liquid under pressure. Some of these relay devices have been discussed in Sect. 26b. See Fig. 241 for an electrohydraulic operator and Fig. 242 for an electropneumatic operator.

Fig. 270—Electric valve operator (Norwood Controls, others). The d.c. signal from the controller is amplified and operates a geared motor driving the valve stem. Valve position is converted to an electrical signal which feeds back into the amplifier circuit where it is compared with the signal. Any difference is amplified to drive the valve to a position exactly proportional to the original d.c. signal.

Fig. 271—Solenoid valves (Automatic Switch Co., others). Solenoid valves are of many types, but most are open-and-shut, either opening with current in the coil, or when the circuit is broken. Consequently, they are commonly used as dump valves and for emergency purposes, leaving throttling applications to conventional control valves. Where more power is required, solenoid valves can be pilot operated.

Fig. 272—Hydraulic valve operator (Republic Flow Meters Co.). Hydraulic operator can be applied to valves, dampers and the like. Primary indication is applied through a spring-balanced beam to a rod controlling leak at L. Oil (or air) pressure is applied both above and below piston F., area above being less. Restriction in line to cylinder below piston makes control of under-piston pressure possible with aid of leak. Piston movements are converted to position of final control element. Through a dash pot they are also transferred to beam for applying feedback action.

Fig. 273 — Hydraulic valve operator (Askania Regulator Co.). Primary measurement positions jet pipe J which projects liquid under 100 lb. pressure against openings leading to two sides of piston. When jet strikes half way between, pressures are equal. Minute deflection will alter pressure on one side or other and drive piston to new position. For most applications where piston should be able to assume intermediate positions, some sort of mechanical feedback would be used to make piston position accurately proportional to jet pipe position. Can be used for driving valves or other final control elements against high pressures since about 90% of static pressure in operating liquid is recovered as effective pressure against piston.

Credits (Companies supplying information especially for this guide)

American Instrument Co.
The Annin Co.
Applied Research Laboratories
Askania Regulator Co.
Automatic Switch Co.
Automatic Timing & Controls, Inc.
Bailey Meter Co.
Baird-Atomic, Inc.
Baker & Co., Inc.
Baldwin-Lima-Hamilton Corp.
Barton Instrument Corp.
Arnold O. Beckman, Inc.
Beckman Instruments, Inc.
Bendix Aviation Corp.
B-I-F Industries
The Bin-Dicator Co.
Branson Instruments, Inc.
The Bristol Co.
Brookfield Engineering Laboratories
Brooks Rotameter Co.
Buffalo Meter Co.
Builders-Providence, Inc.
Burling Instrument Co.
B/W Controller Co.
Conoflow Corp.
Consolidated Electrodynamics Corp.
Coppus Engineering Corp.
Cramer Controls Corp.
Drage Products
Thomas A. Edison, Inc.
Ess Instrument Co.
Fenwal, Inc.
Fielden Instruments Div.
Fischer & Porter Co.
Fisher Governor Co.
Foster Engineering Co.
The Foxboro Co.
Fuller Co.
Fulton-Sylphon Div.
Gardner Laboratories, Inc.
Gems, Inc.
General Electric Co.
Gilbert & Barker Manufacturing Co.
Golden Anderson Valve Specialty Co.
Gow-Mac Instrument Co.
Gulton Industries, Inc.
Hallikainen Instruments
Hammel-Dahl Co.
Hardinge Co.
Hastings-Raydist, Inc.
The Hays Corp.
Helicoid Gage Div.
Illinois Testing Laboratories
Industrial Development Laboratories
Industrial Instruments, Inc.
Industrial Nucleonics Corp.
Inertial Instruments, Inc.
Jarco Services, Inc.
W. A. Kates Co.
Kieley & Mueller, Inc.
King Engineering Corp.
The Kybernetes Corp.
Lapp Insulator Co.
Leeds & Northrup Co.
Manning, Maxwell & Moore, Inc.
Manostat Corp.
Manufacturers Engineering & Equipment Co.
Mason-Neilan Div.
W. L. Maxson Corp.
Milton Roy Co.
Mine Safety Appliances Co.
Minneapolis-Honeywell Regulator Co.
Moore Products Co.
MSA Research Corp.
National Research Corp.
Neptune Meter Co.
Norcross Corp.
Norwood Controls Div.
Nuclear Development Corp. of America
Omega Machine Co.
The Partlow Corp.
Perkin-Elmer Corp.
Permutit Co.
Petrometer Corp.
Philips Electronics, Inc.
Photoswitch, Inc.
Potter Aeronautical Corp.
Proportioneers, Inc.
Pyrometer Instrument Co.
Quarie Controllers
Ramo-Woolridge Corp.
Republic Flow Meters Co.
Rubicon Co.
Arthur C. Ruge & Associates, Inc.
Schutte & Koerting Co.
Shand & Jurs Co.
F. J. Stokes Corp.
The Swartwout Co.
Syntron Co.
Taylor Instrument Cos.
Toledo Scale Co.
Tracerlab, Inc.
United Electric Controls Co.
U. S. Gage Div.
Westinghouse Electric Corp.
West Instrument Corp.
Weston Electrical Instrument Corp.
Wheelco Instrument Div.
Yarnall-Waring Co.

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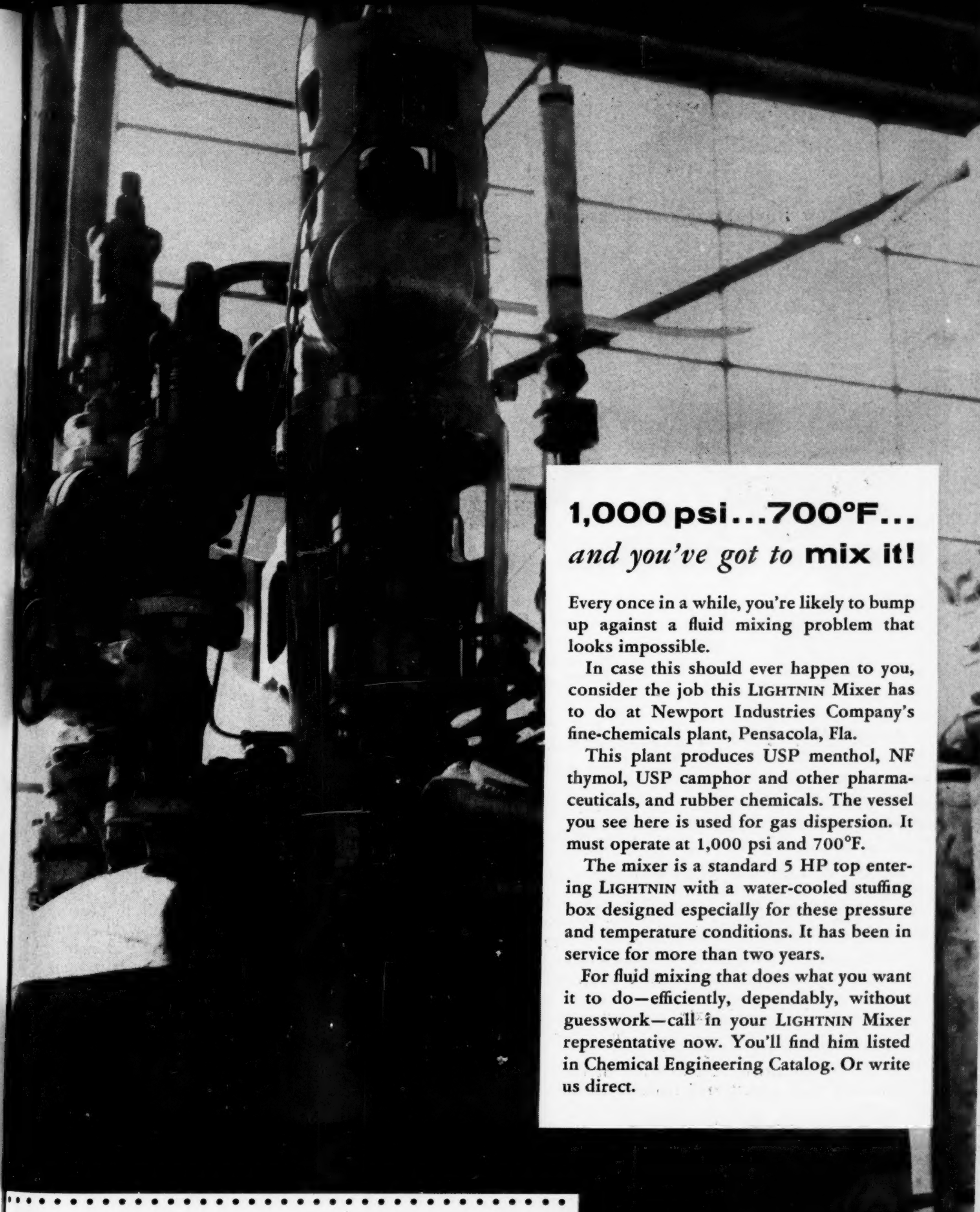


XUM

When You Have Four Components . . .

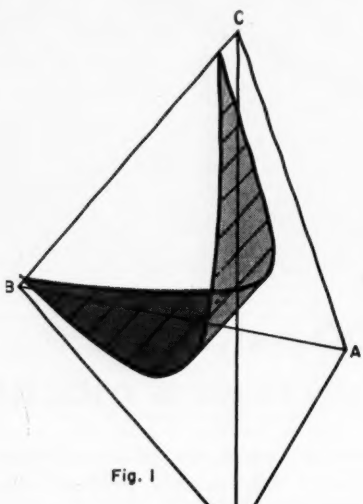


Fig. 1

Single-Binary System

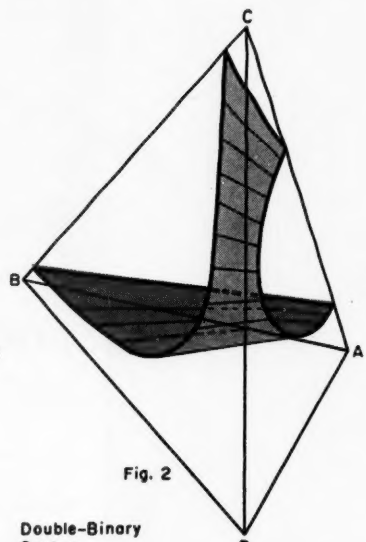


Fig. 2

Double-Binary System

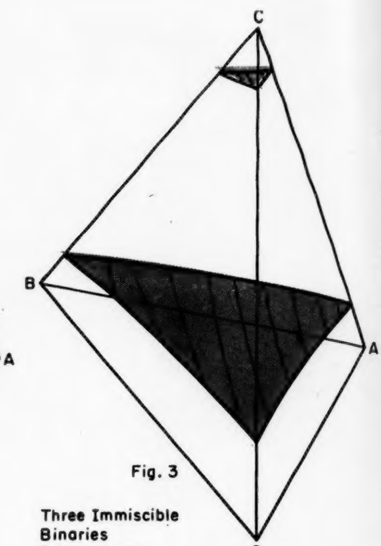


Fig. 3

Three Immiscible Binaries In the System

Design for Liquid-Liquid Equilibrium

If you use mixed solvents for extraction, the phase relations can be baffling. This review should clear up some difficulties.

JAMES O. OSBURN, State University of Iowa, Iowa City, Ia.*

When we use solvent extraction we ordinarily have three components: a solute and two solvents. In our last article in this series (*Chem. Eng.*, May 1957, p. 276) we discussed the phase relationships of three-component systems that apply to liquid extraction.

In some liquid-liquid extraction processes we encounter four components—sometimes even more. These cases are the most common:

- Solute consists of two different components. Both are to be transferred from one solvent to the other.
- Solute consists of two components which we want to separate from each other by distribution between two solvents. This process is called fractional extraction with a *double solvent.* It can be used to give very good separations.
- One of the solvents is a mixture of two substances. By using a *mixed solvent,* we have a control over the solvent power and distribution ratio that we can't get with a pure solvent.

Compared with three-component equilibrium data, four-component data are more difficult to portray and to use. In this month's discussion we'll extend our treatment of liquid-liquid equilibrium to include this more difficult situation. We'll show how some of the difficulties of representation can be overcome or minimized.

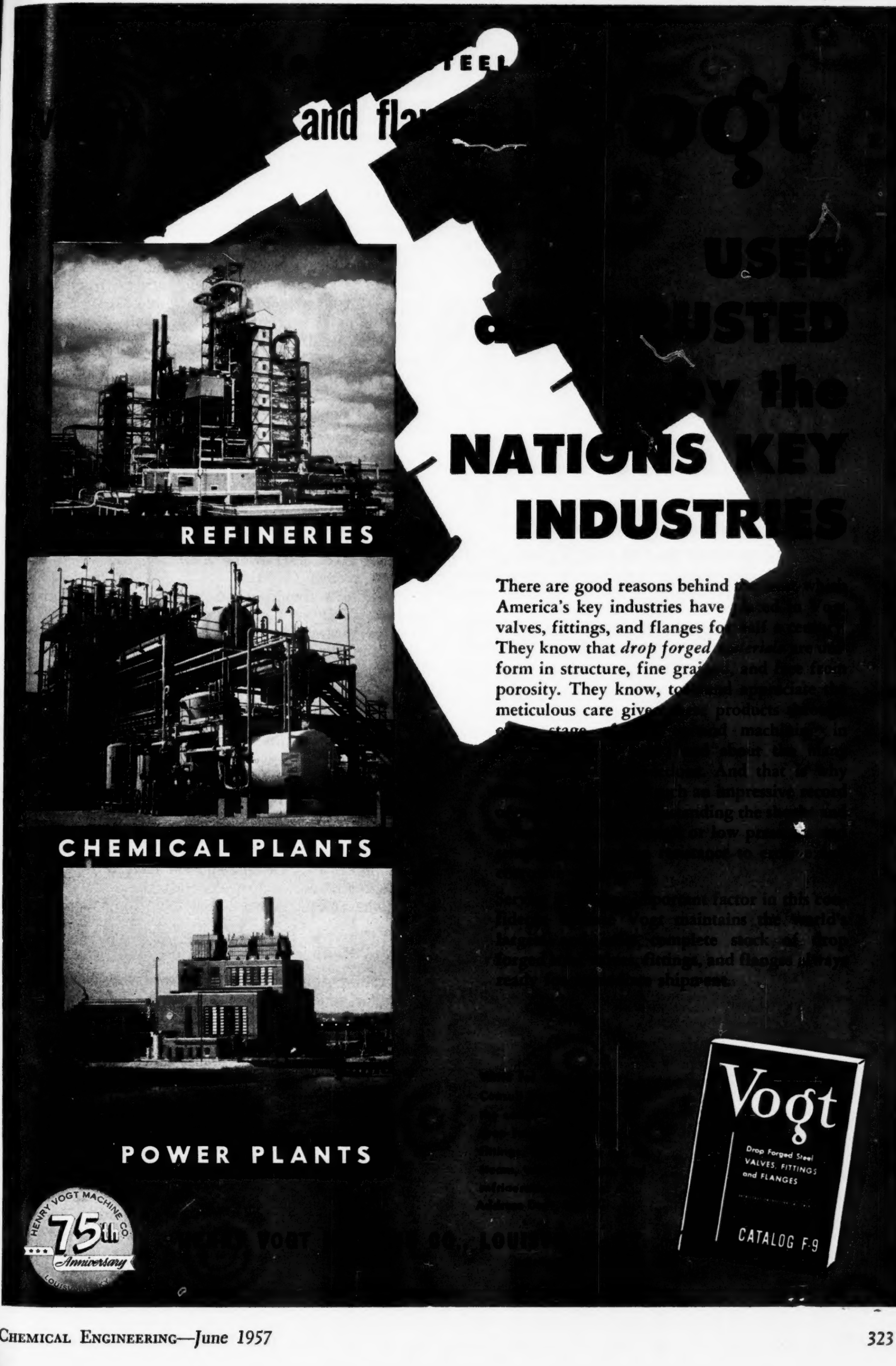
It's Easy With Immiscible Solvents

The techniques we are going to describe will apply to the general case. Assume that the solvents are partially soluble in each other, and that addition of solute increases the miscibility to the point where it is complete.

Fortunately, the situation is usually simpler than this. If we choose solvents wisely, we will usually get two solvents that have a very low miscibility, in order to minimize the solvent loss in the raffinate. In addition, for good separation we ordinarily operate an extractor with dilute solutions. For these solutions the solubilizing effect of the solute is not large.

Under such conditions the equilibrium can be described by a distribution coefficient. This is the

* To meet your author see *Chem. Eng.*, Nov. 1956, p. 415 and April 1957, p. 328.



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ratio of the weight fractions of one solute in the two solvent phases:

$$m_A = X_{AC}/X_{AB}$$

We can write a similar equation for solute D. The ratio m_A/m_D is the selectivity, β, a measure of the ease of separation of A and D from the mixture.

Since we assume the solvents to be completely immiscible, only the solute compositions can vary and the composition of the phase in equilibrium with another phase can be calculated easily.

For example, let's find the C-rich phase in equilibrium with this solution: $X_{BB} = 0.90$; $X_{AB} = 0.05$; and $X_{DB} = 0.05$. The distribution coefficients are: $m_A = 2.0$; and $m_D = 0.5$.

First we calculate X_{AC}:

$$X_{AC} = m_A X_{AB} = (2.0)(0.05) = 0.10$$
$$X_{DC} = m_D X_{DB} = (0.5)(0.5) = 0.025$$
$$\text{Total solute} = 0.125$$
$$\text{Solvent } X_{CC} = 1 - 0.125 = 0.875$$

What If the Assumptions Aren't Valid?

The special case just described is the most useful. However, the general case we're going to describe next is also useful, and it is also of greater theoretical interest.

Let's analyze four-component equilibrium as we have done for fewer components. From the phase rule,

$$F = C - P + 2$$

we get the degrees of freedom, F:

$$4 - P + 2, \text{ or } 6 - P$$

Even when we reduce the degrees of freedom by holding temperature and pressure constant, we have $4 - 1$ or three degrees of freedom for one phase.

We need three dimensions to represent three degrees of freedom. One phase is represented by a volume, two phases by a surface, three phases by a line.

The best we can do on a flat sheet of paper is to draw a picture of what such a three-dimensional would look like. This helps us visualize the relationships, but it isn't good for making calculations.

A quarternary or four-component system is made up of four three-component systems. Since each of these can be represented at constant temperature and pressure on a triangular diagram, when we put them together in a quarternary system we get a pyramid. One of the ternary diagrams appears on each face of the pyramid.

Let's assume that we have components A, B, C and D, of which B and C are partly soluble, and all other pairs are completely miscible. The three-component, partly soluble systems ABC and BCD appear as faces on the quarternary pyramid, and they have a common edge.

We've sketched this diagram as Fig. 1. This diagram is a *single-binary quarternary* when only one pair of components is immiscible.

If two pairs of components are only partly miscible, such as AC and BC, we have a double-binary quarternary. This might look like Fig. 2. When there are three immiscible binaries, one possibility is as shown in Fig. 3. With a little ingenuity you can construct other types.

To Characterize a Quarternary System

Let's go back to the single-binary quarternary diagram and look at some of its features. For our example, we're using the diagram for acetone (A)-water (B)-chloroform (C)-acetic acid (D) at 25 C. as given by Powers in *Chem. Eng. Progress*, Vol. 50, p. 293 (1954).

First, let's consider the two-phase or solubility surface. This surface terminates in the solubility lines in ternary faces ABC and BCD. There are plait points in each of these two ternary diagrams. In ternary liquid equilibrium, the plait point is the composition at which two phases in equilibrium have identical compositions.

In quarternary equilibrium, there is a whole series of plait points forming a line that joins the ternary plait points. This line is on the solubility surface and it is not necessarily straight. Compositions above the plait point are in the C-rich phase, and those below are in the B-rich phase. The compositions in equilibrium might be joined by tie lines, but here the representation becomes too complicated. Tie lines do not have to lie in any particular plane, and to correlate them we have to use some auxiliary two-dimensional diagrams.

How to Reduce to Two Dimensions

Pyramid diagrams can be useful in helping us visualize equilibrium relationships, but we can't use them with any precision for engineering calculations.

We might—at great labor and expense—build a three-dimensional model, and even draw in a number of tie lines. But this would be very unwieldy to use and would have to be a very large model to give us any precision at all. We'll find it much more satisfactory to make a transformation that enables us to work with two dimensions.

Starting with the pyramid diagram, let's take slices perpendicular to edge DB at equal intervals of X_D. This is equivalent to fixing another degree of freedom by fixing the composition of D. When we get down to the solubility surface, each slice will intersect this surface in a solubility line.

Then, as shown in Fig. 4, we superimpose these

Nomenclature (Consistent Units)

A, B, C, D	**Components in a solution**
C	**Number of components**
F	**Degrees of freedom**
m	**Distribution**
P	**Number of phases**
X	**Weight fraction**
β	**Selectivity**
Subscripts	
A, B, C, D	**Of component *A, B, C, D*, etc.**
AA	**Of *A* in the *A*-rich phase**
AB	**Of *A* in the *B*-rich phase**
AC	**Of *A* in the *C*-rich phase**
AD	**Of *A* in the *D*-rich phase**
BB	**Of *B* in the *B*-rich phase**
etc.	

ADSORPTION IS A BASIC CHEMICAL ENGINEERING PROCESS

DARCO Digest

CHEMICALS DIVISION, ATLAS POWDER COMPANY, WILMINGTON 99, DELAWARE • Atlas Powder Company, Canada, Ltd., Brantford, Ontario, Canada

Want to prevent haze?

USE ACTIVATED CARBON

When liquid products—beverages, in particular—look cloudy instead of clear, the consumer is apt to suspect impurities are present. One unfortunate experience can lose you a customer.

To prevent turbidity, take a close look at what causes it. Generally the guilty party is a substance that is at the point of precipitation, due to limited solubility, when the solution is first prepared. Then, due to changes in temperature or other action that lowers solubility, the haze-former falls out of solution.

Most haze-forming materials are large, complex molecules. And these are a natural for removal by activated carbon. People who make sugar for beverage use have to be especially careful about haze. That's why they use DARCO activated carbon to remove floc precursors that might otherwise cause haze when the beverage is in storage. Brewers, too, use DARCO to prevent the "chill haze" that is caused by certain nearly insoluble proteins present in beer.

We're old hands in the haze-prevention business. Call on us for help on your specific problem.

For removing a lot of *color* TRY DARCO KB

If you need to purify a product that has a large amount of color contamination in it, don't figure that activated carbon would be uneconomical. For this kind of application, we have developed a special grade, DARCO KB, that can do the trick for you.

DARCO KB is often our recommendation for decolorizing monosodium glutamate, waxes, oil, and fine chemicals like methionine and plasticizers. Its particular claim to fame is that it has unusually high adsorptive power. Where impurity concentrations are so high that an extra large dosage of ordinary carbon grades would be needed, you can get by with considerably less DARCO KB. At the same time, it has high bulk density; so your filtering, handling and storage costs are reduced.

Before you go overboard on DARCO KB, give us some of the details about your problem. Could be that you're not in as bad trouble as you thought. At any rate, we can probably recommend the best way to tackle your problem, and the best all-around grade of DARCO to use.

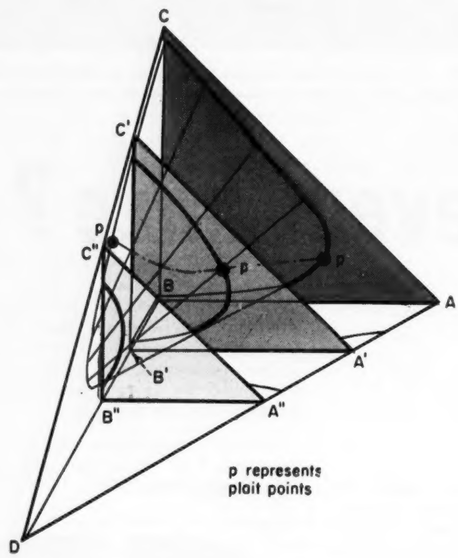
Imagineering with activated carbon —entrapment

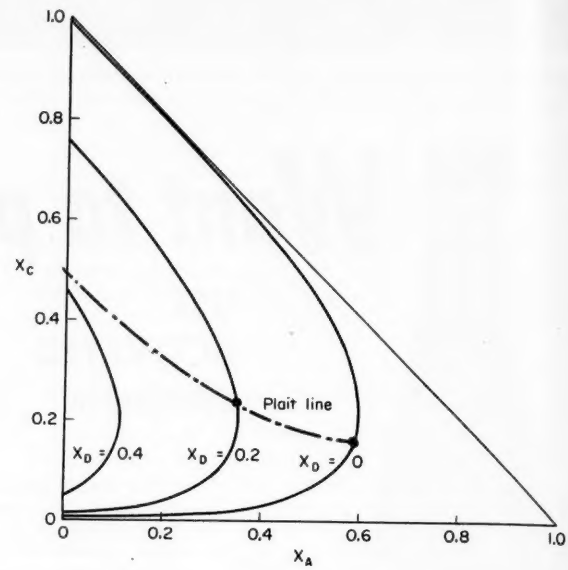
The function of activated carbon in collecting adsorbable materials can be put to other uses than the usual purification applications with which you're familiar. For instance, you can often use activated carbon to entrap materials that you don't want to reach a protected location. This idea has been put to work in oil wells. Surface active materials introduced in the drilling fluids sometimes interfere with the setting of the cement that is poured around the upper well casing. Add carbon to the cement, and the surface active agents collect on it like flies on flypaper.

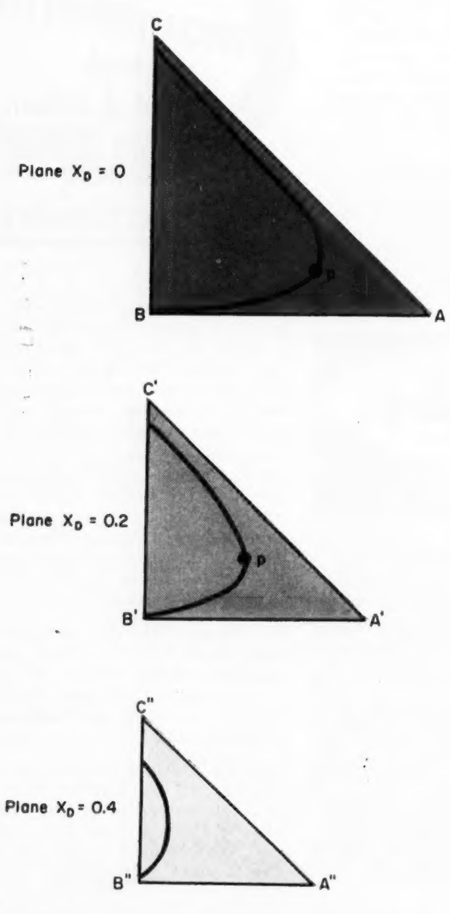
On the same theory, some tire makers have been putting a small amount of activated carbon in tires. Its purpose is to trap black dyes that tend to bleed through to white sidewalls and cause unsightly stains.

Another unusual facet of this kind of application: the carbon stays in the product, instead of getting filtered out. Maybe there are possibilities here for you. We'd be glad to talk over any ideas this thought may arouse.

Slicing Planes Reduce Three Dimensions to Two for Calculation Ease—Fig. 4







lines on our paper and label each with a corresponding value of X_D. Now we have a two-dimensional plot of the four-component equilibrium.

According to Braneker, Hunter and Nash [*Ind. & Eng. Chem.*, Vol. 33, p. 880 (1941)], the saturation surface for the system they studied is the locus of straight lines joining the ternary saturation lines and lying in planes perpendicular to the edge which contains the insoluble pair. What this means in terms of the diagram we are using is that the curves are spaced equidistant in a horizontal direction.

However, this may not be necessarily true for all systems.

The location of the plait line can be shown on this reduced plot. We can show that this diagram is sufficient to represent any point on the three-dimensional solubility curve. For example, let's calculate the plait point composition at $X_D = 0.2$.

From Fig. 4, at this point

$$\begin{aligned} X_A &= 0.35 \\ X_B &= 0.23 \\ X_C &= 0.20 \\ \hline &\ 0.78 \end{aligned}$$

and by difference, $X_B = 0.22$.

We Need Other Diagrams for Tie Lines

Although it represents the solubility satisfactorily, the diagram shown in Fig. 4 doesn't tell us anything about the tie lines. For this, we need two other diagrams.

If we know a composition in the C-rich phase, and want to calculate the composition of the B-rich phase in equilibrium with it, we prepare distribution diagrams like those shown in Fig. 5.

RECIRCULATION MAY BE KEY TO FUTURE GROWTH OF CHEMICAL AND INDUSTRIAL PROCESSES

• AN ADAMS REPORT

Number 2 of a Series

How much water do you need to make: a ton of steel? a ton of synthetic rubber? a ton of bromine? a barrel of beer?

These are not empty questions. They point to a critical problem which confronts management today in its plans for tomorrow. It is more crtical than most of us realize ... for industry today uses as much water as all other users.

Industry's Needs in 1975

Water is vital for chemical and industrial growth. By 1975, industry will require 215 billions of gallons daily. That is a 100% increase over our current industrial consumption ... more than we currently consume for all uses combined.

Competing for this water will be irrigation farmers and the general public. Their combined needs by 1975 will be up 40 billion gallons a day ... possibly even more.

What is the Supply Picture

More than 40% of the communities in the United States already have a critical water supply problem. Yet, to meet the 1975 needs, our supply must be expanded by 50%, at an estimated cost of $50 billion.

Indications are that industry is going to have to bear its part of this cost. Certain communities are already moving to place flat water rates on all users ... regardless of the volume used. Other groups are demanding a national water policy with full Federal Government regulation of natural sources.

Chemical Industry's Stake

Shortage of water can be a most serious threat to the expansion hopes of the chemical industry. A glance at the following table shows why. You need approximately:

20,800 tons of water per ton of	Bromine
2,500 " " " " " "	Synthetic rubber
830 " " " " " "	Viscose rayon
300 " " " " " "	Newsprint
208 " " " " " "	Smokeless powder
15 " " " " " "	Coke from coal

While process refinements may be able to reduce slightly the amount of water needed for each product, the gains will be minor.

Difference Between Use and Consumption

This is best illustrated by the water needed to make a ton of steel. The industrial average is 65,000 gallons (271 tons). In the past, 65,000 gallons of water flowed out of a river through the steel mill and back into the river again for each ton of steel made. In this case, use and consumption are one and the same thing.

On the west coast, a large steel mill now requires only 1,100 gallons of makeup for each ton of steel produced. This steel mill has its own recirculation system which holds several million gallons of water. This water is recirculated at a rate equal to 65,000 gallons per ton of steel produced. The only water consumed is that lost due to evaporation or through leakage. Thus, net consumption has been reduced to 1,100 gallons.

Two Bulletins Available

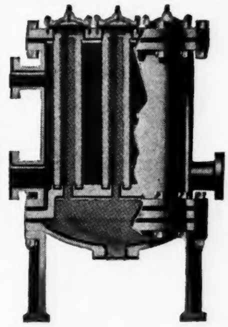
One of the most important pieces of equipment in a recirculation system is a filter. Where high quality process water is needed, diatomite filters will provide an effluent second only to distilled water. Bulletin 651, released by the R. P. Adams Company, Inc., 507 E. Park Drive, Buffalo 17, N. Y., covers this type of industrial water filter.

A second publication, Bulletin 909, covers an Automatic Water Filter which is frequently used in recirculation systems where the water is used for less critical applications. This bulletin is also available on request from the R. P. Adams Company at the above address.

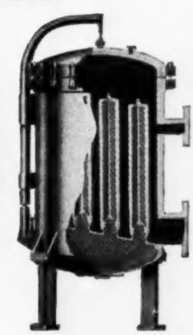
By the way, it takes almost two tons of water to brew a barrel of beer.

NEED A FILTER FOR CORROSIVE LIQUIDS?

Adams CFR are rubber lined filters which meet corrosion problems which require this type construction. Where lead lining is a must, the Adams CFL filter will meet your needs. Each tubular element of either filter may be removed individually for inspection, or replacement.



Adams CVF Filters are available in carbon steel, stainless steel, Monel and Nickel construction. Also constructed with submerged head for personnel safety and with outer jacket for use with steam or refrigerated coolant to maintain desired temperature.



All Adams Filters provide safe cleaning without disassembly by a sudden, high velocity reverse flow of backwash liquid.

Do you have a filtration problem where corrosive liquids must be given a high polish? Where there is danger to personnel? Where there is a problem of temperature control?

The R. P. Adams Company has a line of filters which will solve any one of these problems ... or a combination of all.

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R. P. ADAMS COMPANY, INC. 207 E. PARK DRIVE BUFFALO 17, NEW YORK

R. P. ADAMS COMPANY, INC. JU 57
207 E. PARK DRIVE — BUFFALO, 17, NEW YORK

We have a problem involving the filtration of corrosive liquids. Please send us your Bulletin 431. Also, ask your local representative to call on us.

Name________________ Title________________

Company________________________________

Street__________________________________

City________________ State________________

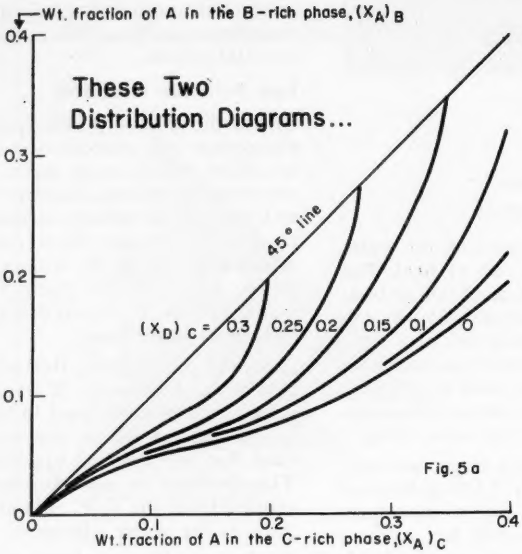


Fig. 5a

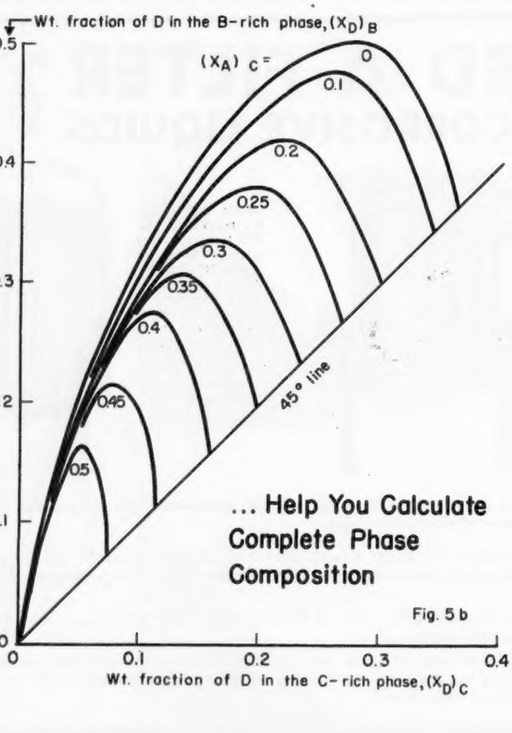


Fig. 5b

Here the equilibrium compositions of the *B*-rich phases are shown as a function of two of the compositions of the *C*-rich phase. One diagram is for the composition of *A*, and one for the composition of *D*. With these and the solubility diagram, you can calculate the complete phase composition.

For example, let's calculate the composition of the *B*-rich phase in equilibrium with a solution whose composition is: $X_{AC} = 0.40$; $X_{DC} = 0.10$; $X_{CC} = 0.42$; and $X_{BC} = 0.08$.

From Fig. 5a, $X_{AB} = 0.22$; from Fig. 5b, $X_{DB} = 0.27$; from Fig. 4 (where $X_A = 0.22$ and $X_D = 0.27$), $X_C = 0.27$. By difference, $X_{BB} = 0.41$.

If we should want to go in the reverse direction and find *C*-rich phase compositions from those in the *B*-rich phase, we would replot the distribution data using X_{DB} and X_{AB} as parameters.

Can We Correlate Tie Lines?

Because of the great difficulty in measuring four-component equilibrium, and because a relatively large amount of three-component data is available, attempts have been made to draw in quarternary tie lines based on the tie lines in the three-component systems.

From the information available, the changes produced by a fourth component are rather regular and predictable. Prince, in *Chem. Eng. Science*, Vol. 3, pp. 175-186 (1954), has developed correlations which worked well for two systems. The biggest difficulty is that there are so few quarternary data for testing correlations.

Therefore, we can not use these correlations with much confidence.

Note This Important Limitation

The diagrams we have described permit us to calculate compositions in a countercurrent extraction process. Powers [*Chem. Eng. Progress*, Vol. 50, p. 293 (1954)] gives an example of this.

In batch extraction we have a composition in the two-phase region and we must find the composition of the two phases into which it will separate. In a three-component system we do this by drawing in some tie lines until we find one that goes through the desired point.

There is no way that we can do this for four components. Thus, we have the paradox that countercurrent extraction calculations are fairly easy, while those for batch extraction are impossible.

When There Are More Than Four

Four of the largest number of components we can handle conveniently and still recognize each one separately. With a greater number we have to resort to the scheme of grouping some of them together to form a "pseudocomponent." By this technique we reduce the number of components to three, which can be plotted on a two-dimensional diagram.

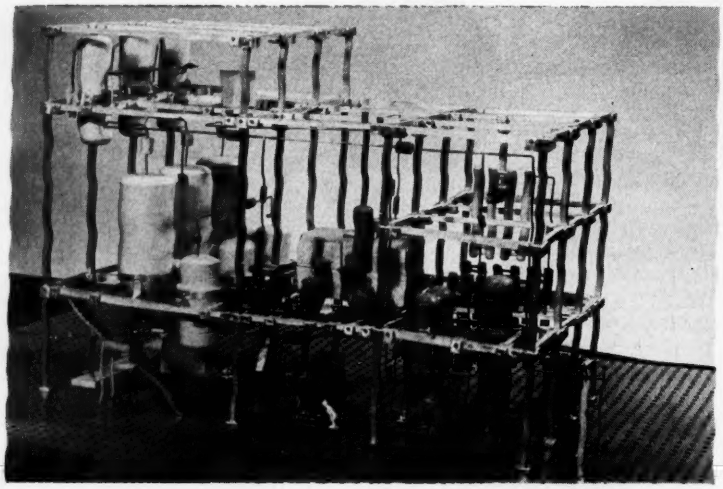
Although this is not strictly correct from the point of view of the phase rule, it works. And this technique has been used with good results for extraction calculations that involve lubricating oils and vegetable oils.

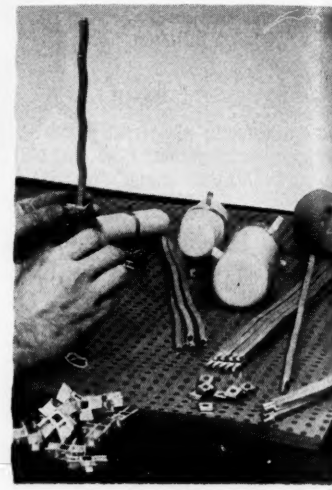
Next Month: Solving Flow Problems

With many thanks to Jim Osburn for this fine eight-part series on physical equilibrium, we'll focus our attention next month on some simplified methods for handling your fluid flow calculations. This two-part CE Refresher series will be authored by Lloyd M. Polentz of Whittier, Calif.—EDITOR

PRACTICE . . .

PLANT NOTEBOOK EDITED BY T. R. OLIVE





Do-It-Yourself Models for Layout Studies

Preliminary layout models, almost as realistic as a professional job, are not hard to produce.

★ *March Contest Winner by*
William B. Speir
Staff Engineer, Industrial Planning Dept., The Rust Engineering Co., Birmingham, Ala.

In recent years there has been a many-fold increase in the use of scale models at various stages of the design of chemical process plants. Many articles have dwelt on the advantages of using models. It will not be necessary to repeat them here, except to point out that much money is being saved on drafting costs alone through their use. Our experience at Rust Engineering Co. has been similar to that of other companies using design models. We find that appreciable savings can be effected, while a better job can be done through their use.

The idea of "Erector-set" kits for model building is not new and several are available commercially. However, the models made from such kits are only a crude representation and need a very active imagination to visualize what the finished plant will look like. Realism and accuracy have taken a back seat in the effort to achieve flexibility. Even so, these models are useful, which speaks well for the power of the tool of three-dimensional presentation.

At Rust we experimented extensively with various types of engineering models, uncovering the inherent shortcomings which reduced their effectiveness. We found that a good system for preliminary models should have the following characteristics: (1) Permit models to be set up quickly; (2) be flexible enough to allow changes to be made quickly to try out various arrangements; (3) be as realistic as possible to gain maximum value in the design phase of a project.

We felt that if these characteristics could all be incorporated in the system, we would have developed an extremely valuable tool for deciding on plant layouts. In many model systems the building is slow and the permanent character of the result serves to discourage major changes once a model is set up. The main function of a preliminary model, however, is to give engineers a device to test the value of different arrangements as they occur to them. So, in achieving ease of construction and flexibility, we would have restored the preliminary model to its proper place in the design picture.

Rust's Industrial Planning Department therefore took what it had learned about models and developed a system with both flexibility and realism. Although each project differs to a greater or lesser degree from the last, the components of the new system can easily be modified to fit a wide variety of installations. The system is especially useful in multi-story layouts.

In addition to the criteria of flexibility and realism, we set up certain other goals for our de-

* See p. 336 for Contest rules and next month's winning article.

sign: (1) That the system should allow equipment to be supported at any location or elevation desired; (2) that the resultant model should photograph well; (3) that it could be set up and modified by engineers, rather than professional model makers; (4) that it be sturdy and self-supporting; and (5) that it permit piping and materials handling to be shown.

The heart of the system is a pegboard base on which extruded aluminum columns can be set upright. Each column has a turned section at one end and a hole drilled in the other. The turned end fits the pegboard, but also fits the hole so that column sections of various lengths can be put together.

Floor beams are supported from cast aluminum brackets that slide up and down on the columns and can be secured at the proper elevation by set screws. The floor beams fit into sockets in the brackets and they also are secured by set screws. Column brackets are of four kinds: two-socket 180° and 90° arrangements, and three- and four-socket arrangements. There is also a one-socket floor-beam bracket which enables a cross beam to be supported by a main beam. All the brackets can be tightened or loosened with the same hexagon wrench, the only tool needed in setting up or making changes in column spacing, floor elevation or floor beam location.

Floor beams are of white pine, sprayed with aluminum paint. This gives the entire structural frame an unobtrusive neutral color which photographs well and does not detract from the equipment shown. Long beam strips are easily cut to any length desired for a needed span.

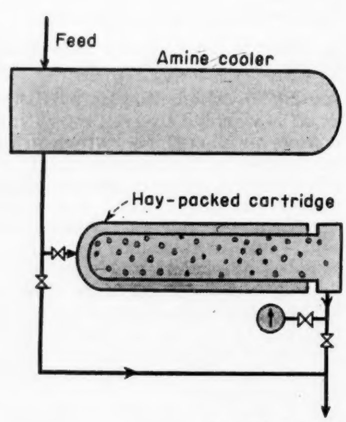
Certain types of standard machines and equipment are bought from model supply houses, including pumps, motors, stairs, ladders and gratings. Special equipment can be made by a model maker or by a pattern shop or machine shop. However, we have found that we can make our own more conveniently. Equipment models are then painted according to type, so as to stand out when mounted in the aluminum framing.

Equipment-supporting lugs are bent from aluminum strips and clamped to the sides of the equipment with small rubber bands. The lugs can be moved up and down to determine proper elevation. They support equipment firmly, yet permit ready changes.

Piping can be shown effectively with $\frac{1}{16}$-in. brass wire, true outside diameter being shown by short lengths of tubing threaded at intervals on to the wire. Valves are mounting directly on the wire and pipe joints are formed by soldering the pieces together. Piping interferences often show up in the piped model, requiring relocation of equipment. The most economical piping arrangements are readily worked out using this easily malleable wire.

As a result of this development, we feel that our engineering personnel now have a tool which enables them to arrive at the best possible layouts in the shortest possible time. Furthermore, the design engineer can assemble models and make changes, even though he is not a trained model maker. Our engineers find the preliminary layout model, or plant mockup, as valuable in designing an efficient physical facility as is the pilot plant in designing an efficient chemical process.

Furthermore, we find the initial cost of setting up such a system to be quite modest. In fact, it can be justified when the first model is assembled. Since the various items can be used over and over again, indefinitely, cost per model becomes very small. And with experience, we continue to improve and simplify the components of the system. As other organizations undertake to "roll their own" it is sure they will do likewise.



"Hay Filters" Clean Up a Difficult Problem

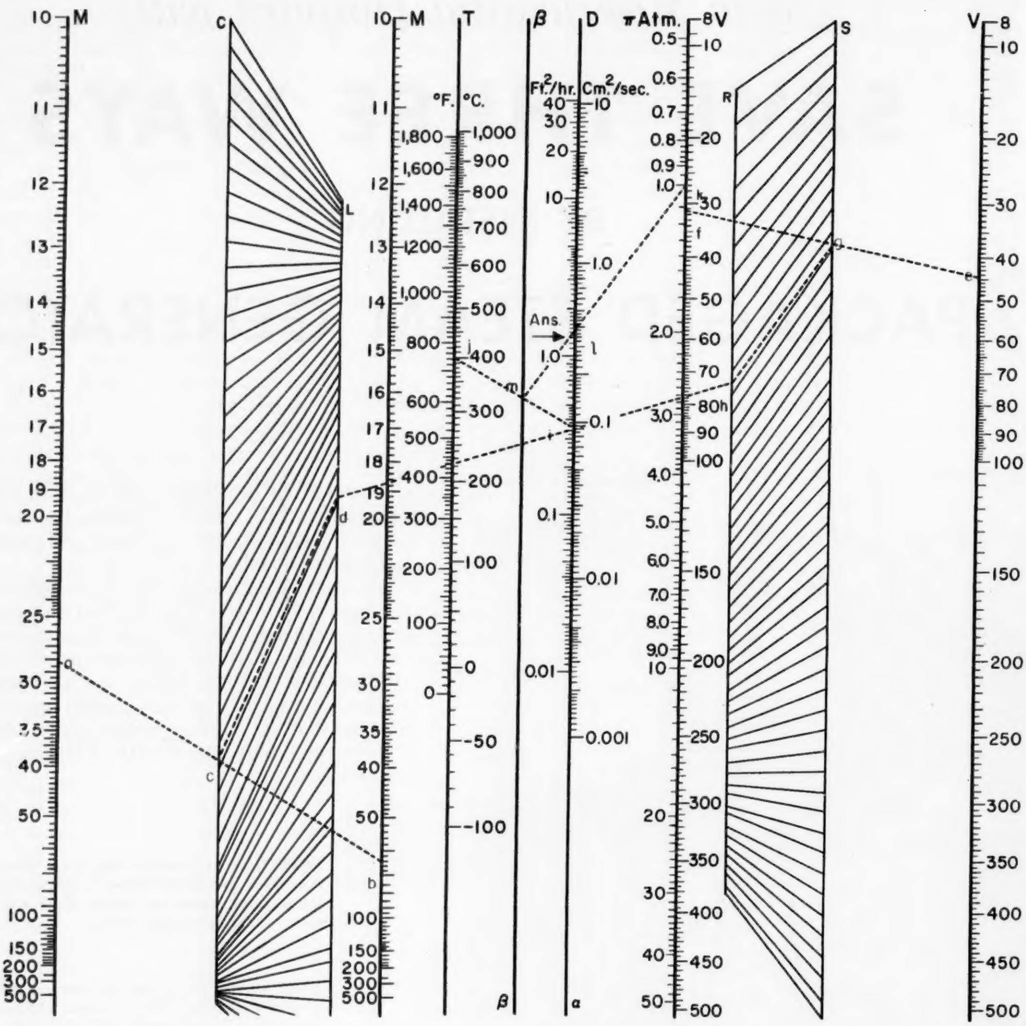
Thomas Garcia B. and
Ismael Rodriguez L.

Respectively, Research Chemist
Monsanto Chemical Co.,
Texas City, Tex., and
Chief Operating Engineer,
Petroleos, Mexicanos,
Reynosa, Tamps., Mexico.

When they were first installed, precoated pressure filters were used in two new Girbotol plants put on stream by Petroleos Mexicanos, at Poza Rica, Ver., Mexico, in 1950. These were intended to remove insoluble solids produced by the decomposition of the monoethanolamine, and by action of the H_2S, CO_2 and water on the system. The solids consisted mainly of iron sulfide and their quantity was enough to make the precoat filters uneconomical.

One of our associates had previously seen an unusual type of pressure filter packed with hay in use in the United States. We designed such a filter, consisting of a perforated inner cartridge packed with hay and sealed concentrically within an outer cylinder into which the dirty solution from the reactivators was introduced under a pressure of $2\frac{1}{2}$ kg./cm.^{2}

The solids content of 30-45 ppm. of suspended matter was reduced by passage through the hay packing to about 5 ppm. When solids had accumulated to the extent that outlet pressure of the filter had dropped to 1 kg./cm.^{2} we isolated the filter and opened the bypass, removing the filter cartridge for immediate replacement with a second cartridge containing new hay. The first was then cleaned and filled with new hay, for later use.



Diffusion in Binary Gaseous Systems

This chart needs only the molecular weights and volumes to give gaseous diffusion coefficients.

L. K. Doraiswamy
Chemical Engineering Dept., National Chemical Lab., Poona, India.

Spangenberg[3] developed a nomograph for solving the cumbersome Gilliland equation[2] which estimates diffusion coefficients for binary gaseous systems. Spangenberg tabulated values of a/b for various gaseous systems, thus limiting easy use of the chart to the systems tabulated. In the equation:

$$D = B\,(T^{3/2}/\pi)\,(a/b)$$

$a = (1/M_A + 1/M_B)^{1/2}$ and $b = (V_A^{1/3} + V_B^{1/3})^2$. Often it is necessary to evaluate D for other gas combinations and it is inconvenient to calculate the a/b ratio. For example, we may need to calculate the effective diffusion coefficient of a gas in a system of n components by evaluating the diffusivities of all the binary combinations of that gas with the remaining $(n - 1)$ components.[1]

To simplify the problem the accompanying chart has been designed to apply to any binary gas system. The terms a and b are separately evaluated on the chart, whereupon the nomographic solution of the remainder of the equation is easy.

Two identical M-scales are provided for determining a, either being used for M_A or M_B. Similarly, two identical V-scales solve for b. The auxiliary lines C and L and their tie lines solve for a, while the auxiliary

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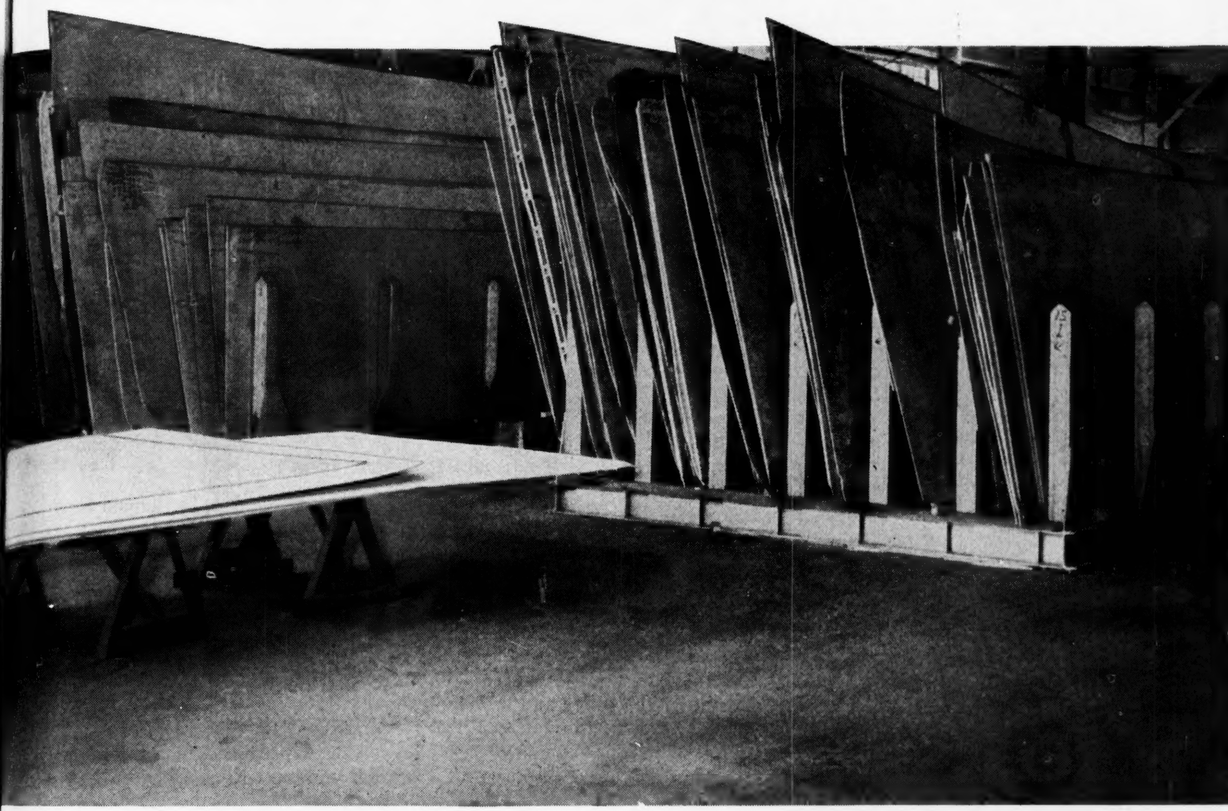

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Nomenclature

D	**Diffusion coefficient; B will be 0.0043 if D is in cm.²/sec.; it will be 0.0166 if D is in ft.²/hr.**
B	**Gilliland constant.**
M_A, M_B	**Molecular weights of component gases.**
T	**Temperature, °K.**
V_A, V_B	**Molecular volumes of the component gases at their normal boiling points, cm.³/g.-mole.**
π	**Pressure, atm.**

lines R and S and their tie lines solve for b. Both appear on the nomograph as their respective logs. It will be noted that reference line α coincides with the D-scale while the π-scale coincides with one V-scale.

Example—Determine the diffusion coefficient for the system nitrogen-sulfur dioxide at 400 C. and 1 atm. The molecular weights are: N_2 = 28 and SO_2 = 64. The molecular volumes are: N_2 = 31.2 and SO_2 = 44.8.

Solution—Connect $M_A = 28$ on either M-scale with $M_B = 64$ on the other (points a and b), marking point c. Follow the tie line to point d. Similarly, connect $V_A = 31.2$ on one V-scale with $V_B = 44.8$ on the other (points e and f), marking point g and moving along the tie line to point h. Join points d and h, marking point i on reference line α. Connect $T = 400$ C. (point j) with point i, locating point m on reference line β. Connect $\pi = 1$ (point k) with point m and read $D = 0.383$ cm.²/sec. at point l. The calculated valve is $D = 0.383$ cm.²/sec.

This nomograph applies to any binary gaseous system, except for the few gases of M.W. < 10. The error resulting from use of the nomograph will be less than 5%.

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2. Gilliland, E. R. *Ind. Eng. Chem.*, **26**, 681 (1934).
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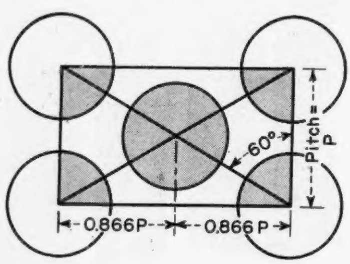


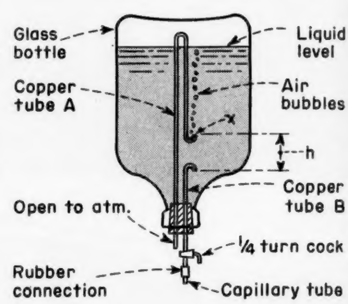
Quick Approximation for Exchanger Diameter

P. V. Folchi
The Chemical & Industrial Corp.
Cincinnati, Ohio.

It is often necessary to find the approximate diameter of a heat exchanger for layout or estimation purposes. The method shown in the sketch is approximate, but accurate enough for preliminary use.

Assume 60° triangular pitch. The total area for two tubes (shaded areas in the sketch) is very nearly that enclosed in the rectangle, or $P \times 2 \cos 30° P = 2 \times 0.866 P^2$; and the area for one tube is $0.866 P^2$, or half that amount.

Hence, if we have 100 tubes of ¾ in. O. D. on 1 in. triangular pitch, area = $0.866 \times 1^2 \times 100 = 86.5$ sq. in. The diameter of the bundle = $(4 \times 86.5/\pi)^{\frac{1}{2}} = 10.5$ in. Allow ½ in. between the outside of the tubes and the shell or 10.5 + 1 = 11½ in. Call the shell diameter 12 in.



Use Any Container for a Constant-Head Feeder

K. J. Johnson
Chemical Engineer,
Bahrain, Persian Gulf.

For still another version of an old constant-head feeder idea, note the sketch above. Air entering the vessel through copper tube A creates a pressure at x which is always atmospheric, provided the level of liquid does not fall below x. Therefore the head on the capillary discharge tube will remain constant at h, and the discharge rate will remain constant. Discharge rate can be adjusted by changing capillary jets or head h.

Air tube A has two bends, the upper one being a seal to prevent water from flowing from this tube. The lower bend insures free discharge of the air bubbles as liquid leaves the feeder. Tube B also has a bend, to prevent sediment from being drawn into the capillary jet.

NEXT MONTH: Design Accuracy Into Your Decanter
By Chesman A. Lee, Winner of the April Contest

★ How Readers Can Win

$50 Prize for a Good Idea—Until further notice the Editors of *Chemical Engineering* will award $50 cash each month to the author of the best short article received that month and accepted for the Plant Notebook.

Each month's winner will be announced in the issue of the second following month, and published the third following month.

$100 Annual Prize—At the end of each year the monthly winners will be rejudged and the year's best winner awarded an additional $100.

How to Enter Contest—Any reader (except McGraw-Hill employees) may submit as many contest entries as he wishes. Acceptable material must be previously unpublished and should be short, preferably not over 500 words, but illustrated if possible. Acceptable non-winning articles will be published at space rates ($10 min.).

Articles may deal with plant or production "kinks", or novel means of presenting useful data, of interest to chemical engineers. Address Plant Notebook Editor, *Chemical Engineering*, 330 West 42nd St., New York 36, N. Y.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CE Flow File—VI

Flow: Heat Exchangers, Pipes

Maxey Brooke, Chemical Engineer, Old Ocean, Tex.
(For author biography see *Chem. Eng.*, Jan. 1957, p. 298)

20. Liquids

APPLICATION

Flow of liquids through the shell side of heat exchangers

FORMULAS

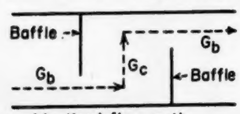
Parallel with tubes: $P_b = 3.76G_b^2/10^6S$

Across tubes, streamline flow: $P_c = \dfrac{8.37NG_c\mu}{10S(P' - D)}$

Across tubes, turbulent flow: $P_c = \dfrac{198G_c^{1.8}\mu^{0.2}N}{10^6S\,(P' - D)^{0.2}}$

NOMENCLATURE

P_b = Pressure drop through baffle opening, psi.
P_c = Crossflow pressure drop, psi.
G_b = Mass velocity through baffle opening based on the area of opening less the tubes passing through it, lb./sq.ft., sec.
G_c = Maximum crossflow mass velocity, lb./sq.ft.,sec.
S = Specific gravity (water at 60F = 1.0).
N = Total number of tube-rows crossed.
μ = Viscosity, centipoises.
P' = Tube pitch, in.
D = Outside tube diameter, in.



Idealized flow path

NOTES

To correct for the viscosity gradient in non-isothermal flow, divide P by $1.10(\mu/\mu_w)^{0.25}$ in the streamline region and $1.02(\mu/\mu_w)^{0.14}$ in the turbulent region. Here μ is viscosity at the average fluid temperature and μ_w is viscosity at wall temperature.

Use table to find Reynolds number at transition from streamline to turbulent flow.

P'/D	N_{Re}
1.20	210
1.25	175
1.30	125
1.40	100
1.50	80
1.75	55
2.00	42

REFERENCE

D. A. Donohue, *Pet. Refiner*, Nov. 1955, pp. 175–184.

21. Liquids

APPLICATION

Flow of liquids through heat exchanger tubes

NOMENCLATURE

P = Pressure drop, psi.
w = Flow per tube, lb./hr.
μ = Viscosity, centipoises
L = Length of tubes, ft.
D = Inside diameter of tubes, in.
S = Specific gravity (water at 60F = 1.0).
N_{Re} = Reynolds number.

REFERENCE

D. A. Donohue, *Pet. Refiner*, Nov. 1955, pp. 175–184.

FORMULAS

Streamline flow, N_{Re} less than 2,100
$P = 6.55w\,\mu L/10^7DS$

Turbulent flow, N_{Re} between 5,000 and 10^7
$P = 8.57w^{1.8}L\mu^{0.2}/10^9D^{4.8}S$

NOTES

Add $6D$ to the tube length for each pass to take care of enlargement and contraction loss.

To correct for the viscosity gradient in non-isothermal flow, divide P by $1.1\,(\mu/\mu_w)^{0.25}$ in the streamline region and by $1.02\,(\mu/\mu_w)^{0.14}$ in the turbulent region. Here μ is viscosity at average liquid temperature and μ_w is viscosity at wall temperature.

22. Liquids

APPLICATION

Pressure drop due to sudden enlargement of pipe cross section

FORMULA

$$P = 0.00112SV^2\left(\frac{1}{D_1^2} - \frac{1}{D_2^2}\right)^2$$

REFERENCE

Schutt, *Trans. ASME*, **Hydraulics, 51**, p. 83, (1929)

NOMENCLATURE

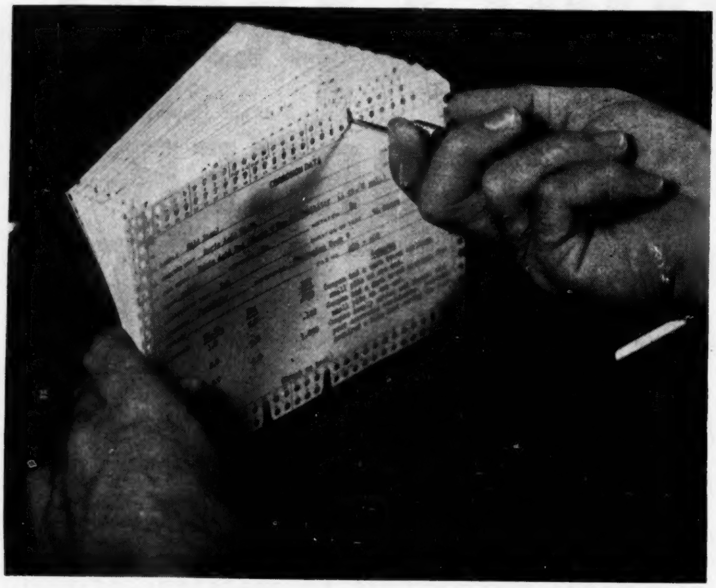
P = Pressure drop, psi.
S = Specific gravity of liquid (water = 1.0).
V = Flow, gpm.
D_1 = Diameter of upstream section, in.
D_2 = Diameter of downstream section, in.

NOTE

For discharge into a large tank, consider $1/D_2$ as equal to zero.

Correction—8. Water

Add to NOMENCLATURE: H = Pressure at gage, ft. of water (*Chem. Eng.*, Mar. 1957, p. 294)



New Punched Card System Will Help You . . .

Organize Corrosion Data

Designed for everyday use, here is how American Potash and Chemical's new, simple, fast and accurate punch card system eliminates frustrating file searching.

G. T. Garrett and O. Osmon, Jr.
American Potash and Chemical Corp., Trona, Calif.*

Filing corrosion data is a difficult job. Data can be classed under solution or environment tested, under the material tested, by the author, date, or section of the plant concerned. Or under any of a number of equally good headings.

Everyone has had the experience of attempting to look up specific data and, unless a very large cross file is maintained, checking every category but the correct one. Or equally frustrating, is to come upon so many items filed in one broad subdivision that data is overlooked or finding it is an onerous task.

* Meet your authors on page 369.

A very simple answer to this dilemma is to record the data on punched cards, and code as many different indexes on the holes as required. This is the solution practiced by the NACE,[1] who sell ready-punched corrosion data files abstracted from literature, and by the International Nickel Company[2] for their extensive corrosion files. Very exhaustive filing systems have been developed by both these organizations to serve a most useful function. However, the tremendous size and complexity of their files tend to make them unsuited for the every day use of most companies.

The corrosion section of the American Potash & Chemical Corp. at Trona recently faced the problem of an overgrown file. We decided to convert to a punched card system, and develop an individual, simplified indexing code.

Reasons for this choice, and the system developed, make an interesting account of the application of punched cards.

Need for Punched Cards

The corrosion section at Trona has been in existence as a group for more than eight years. It has run thousands of corrosion tests, both in the laboratory and the plant.

Tests run under actual conditions, or simulating specific environments, are much more useful than literature references. Therefore, a careful record was kept of these tests on 3 in. x 5 in. cards. They were filed under the section of the plant concerned. Or, if not pertinent to any one plant area, under one of a few general categories.

This system worked well until the collection became so large that finding data was next to impossible for anyone but the corrosion engineer. In view of the success experienced by the NACE and various research groups[3] with punched cards, it was a natural decision to convert the old system.

How System Works

A punched card is merely a file card, upon which information can be recorded and then coded, by "punching out" a series of numbered holes found grouped on the card.

The simple hand-sorted system employs rows of holes around the edges of the card which can be punched to give an open edge in the desired positions. Then, as the photographs illustrate, in searching for information, needles can be used to remove the unwanted (unpunched) cards, leaving only the pertinent ones.

Code systems can be as simple or as involved as desired, with

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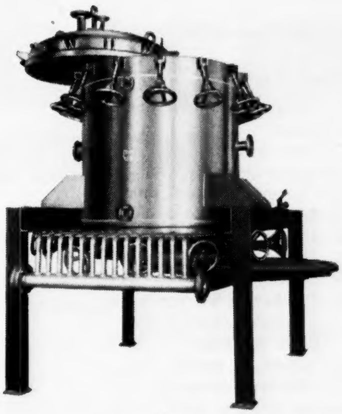

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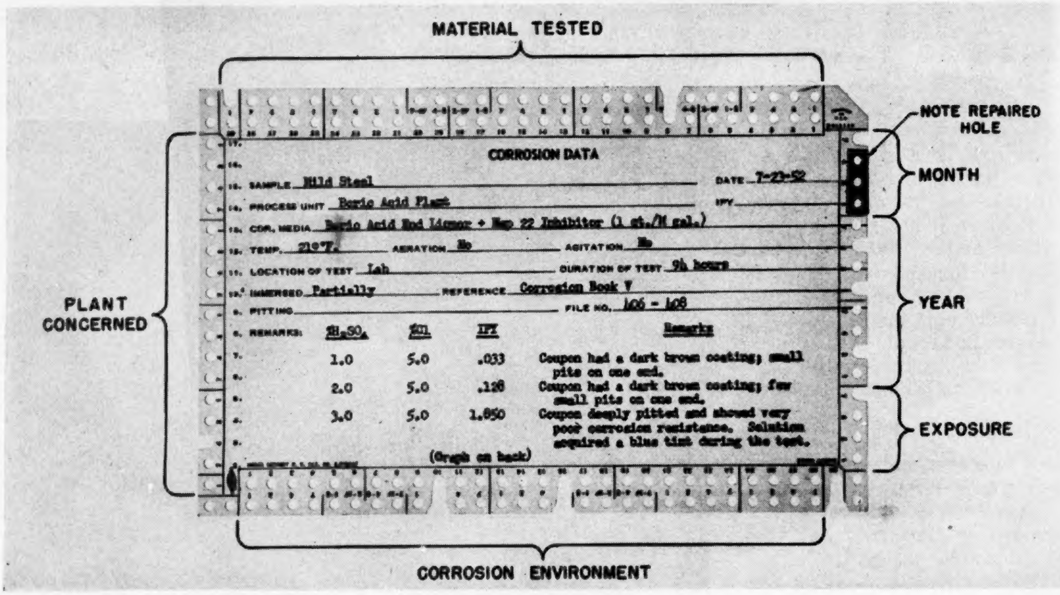

Code for Punched Cards

A. Plant Area

1. Aghi (agricultural potash)
2. Borax
3. Boric acid
4. Carbonation
5. Chemhi (chemical potash)
6. Bromine
7. Lithium carbonate
8. Phosphoric acid
9. Concentration
10. Pyrobor, V-bor (anhydrous, pentahydrate borax)
11. Soda products
12. Sulfate of potash
13. Whittier laboratory
14. Los Angeles plant
15. Experimental
16. Henderson plant
17. San Antonio plant

B. Materials

1. Aluminum
2. Copper and copper alloys
3. Carpenter 20
4. Cast materials
5. Hastelloys
6. Inconel, Monel, etc.
7. Mild steel
8. Nickel
9. 304 stainless
10. 316 stainless
11. 400 series stainless
12. All other stainless, incl. 310 stainless
13. Titanium, tantalum, zirconium
14. Heavy metals (lead, silver)
15. Low alloys
16. Other high alloys
17. Plated and coated metals
18. Acid brick
19. Portland cement
20. Glass and ceramics
21. Fabrics
22. Fiberglass
23. Phenolics
24. Rubber and neoprene
25. Other plastics
26. Wood
27. Karbate

C. Corrosion Media

1. Fresh water
2. Valley well water
3. Cooling tower water
4. Lake brine
5. Carbonated brine
6. Neutral brine
7. Alkaline brine
8. LiOH, Li_2CO_3
9. Other lithium compounds
10. Bromine
11. Bromine compounds
12. Borax
13. Boron compounds
14. Organo-borons
15. HF and fluorine compounds
16. Caustic and ammonia
17. HCl
18. NaCl
19. KCl
20. H_2SO_4
21. Na_2SO_4
22. K_2SO_4
23. Na_2CO_3
24. H_3PO_4
25. Gases
26. Steam
27. Organics

D. Conditions

1. Partial immersion
2. Vapor or intermittent wetting
4. Dry exposure
7. Inhibitor

the limitation that beyond a certain point the number of needle separations increase in proportion to the complexity.

Coding systems and techniques are numerous, and have been amply described by several books on the subject.[4, 5]

Simplest method is to let each hole represent a specific subject. For example, if there are 29 holes along the top of the card, they could represent 29 different metals, one for each hole. A similar coding could be made along the sides and the bottom. This method has the advantage of very easy sorting, but of course, it limits the number of items that can be coded.

Next in complexity, four holes can be numbered in a group or field, such as 7, 4, 2, and 1. Then, by punching various combinations of these numbers, their punched sum add up to any number between 1 and 14. Punching 2 and 4 represent 6; 1, 2, and 7 represent 10; and so on. In this manner the number of items

URANIUM

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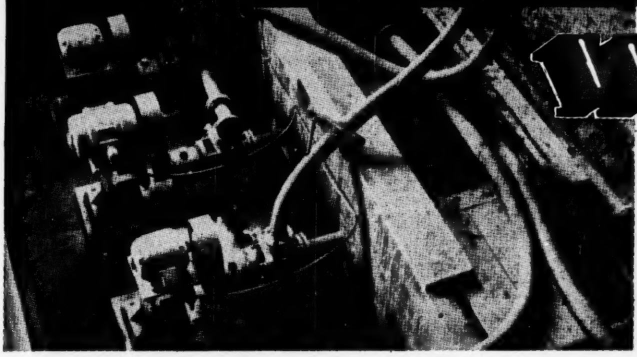
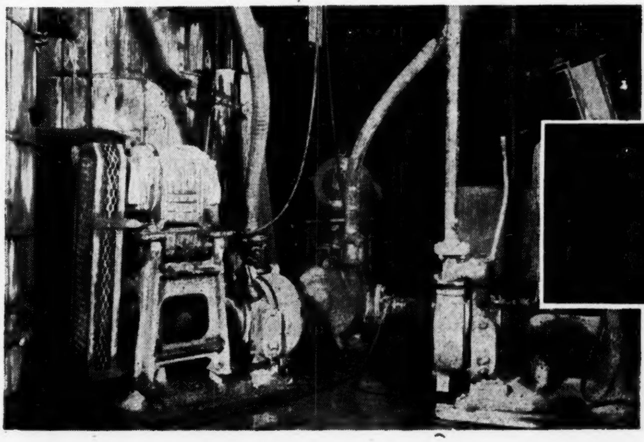


WILFLEY ACID PUMPS receiving vanadium and uranium leach liquors from leach tanks and pumping them to various treatment tanks.

WILFLEY SAND PUMPS receiving the classifier overflow and pumping the material to the sand slime separation circuit.



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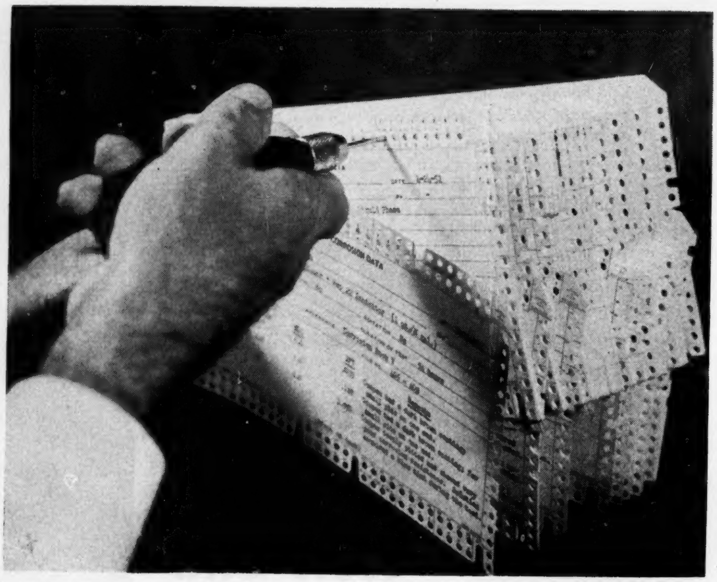

FANNING CARDS by pulling needle back perpendicular to card axis.

coded can be almost limitless by using as many such fields as required, singly or in groups.

Two fields allow numbers up to 100, three fields numbers through 1,000, and so on. Of course, the more plentiful the grouping of holes in fields, the more needle work required in sorting, for several insertions are necessary to obtain a single number.

Often a combination of a few grouped categories and as many single-subject holes as possible will give the best system. Also, double rows of holes can be used to give added coding possibilities. Obviously many other coding systems are possible,[4, 5] and there are often reasons, of course, for establishing a complex system. However, for the purposes of this article, it is not necessary to consider these details.

Selecting Most Useful System

The selection of the indexing system is the most important and difficult part of establishing a punched card file. It is true that there are generally enough holes so that a system can be modified long after it has been established. But it is best to establish something close to the final form at the start.

The first problem is to decide what size cards to use. They are available in many sizes, and include cards with pockets and those designed for the attachment of previously recorded data. Naturally, the larger the size, the more holes there are around the border, allowing a more extensive direct code. But this is usually a secondary consideration.

Generally the smallest size that can comfortably hold all of the data is the best; for AP&CC's case, 5 in. x 8 in. cards. Sufficient data can be typed on such a card, and it is large enough to hold a small graph (generally all that is justified within the accuracy of corrosion data).

Next, the form of the card has to be considered. If pre-printed cards are to be used, the coding system needs to conform to the system or numbers existing on the card. If a blank card is be printed to order, more freedom with the code is permissible, and card space would be better utilized. The latter procedure was deemed superior by the American Potash corrosion group, since the additional cost was slight.

In establishing the code, a primary object was simplicity. This insures an absolute minimum of needle sorting to find the desired information. But it is a compromise with completeness and results in a few extraneous cards collected during a search. These have to be manually sorted out. However, with a comparatively small file, this was still the most rapid and efficient approach.

It was also decided that the code must be clear enough so people not familiar with it, or even with corrosion, could find information easily. With these generalities established, the details of the code were worked out.

Usually, the most important heading would be that of the plant to which the data pertains. Column A of the table lists these for American Potash & Chemical Corp. Most of the plants are for the Trona location, since that is where most of the data has been taken. But entries are also shown for the three other plant locations of the company and one other laboratory. This number can be expanded as the occasion arises. For now, however, it conveniently fits on the left side of the card in consecutive numbers from 1 to 17.

The next most valuable index was deemed to be that of material tested.

A staggering number of materials could be listed, of course. But ordinarily the same, rather limited group are considered and used over and over, while others are encountered only occasionally. This allows a simplified arrangement, for many of the less common materials can be indexed under the same number.

Column B shows the materials listed at American Potash, and indicates that they are coded into consecutive numbers on the inside row of the top edge. Later expansion can be effected by completing the row and utilizing the upper row of holes.

The next grouping, that of the corrosion environment, is perhaps the most difficult to keep uncomplicated.

Since the number of specific environments is almost without end, it was decided, for the sake of simplicity, to generalize, even if the result was an occasional overly-broad division. To this end, the chemicals most frequently encountered were listed,

as were the waters and the general types of brine.

Multiple punches would often be expected in this grouping. For instance, to indicate a neutral brine (punch neutral brine) which is predominantly sodium sulfate (punch Na_2SO_4) and sodium chloride (punch NaCl).

If there were no predominate salts present in a brine (such as an end liquor with many components) only the "alkaline brine" would be punched, along with the plant the brine occurs in, such as "Soda products." Either of these two examples would result in a large number of cards if only the plant and environment indexes were used in a search. But all of the cards should contain data somewhat pertinent to the question, and hand sorting would eliminate the extraneous information quickly.

To list more specific environments would require many more numbers, and the sorting would probably be even more time consuming if the 7, 4, 2, 1 fields had to be employed. As the system illustrated here is set up (Column C, table), the first 28 numbers of the inside row of the bottom of the card are used, leaving the outside row for future expansion.

To complete the file, the first three 7, 4, 2, 1 fields on the right-hand side are used for the date. The first is the month, and the second two the year. The lower 7, 4, 2, 1 field (Column D, table) is used to augment the description of the environment; 7 to indicate whether an inhibitor had been used, 4 for a dry exposure, 2 for vapor or intermittent wetting, and 1 for a partial immersion. If holes 4, 2, and 1 are left unpunched, total immersion is implied.

Results of the System

The new file has been in use for about 10 months, and has thus far been highly successful. Data is easy enough to find so that it is now checked before specifications are made or new experiments run. This was not always the case previously.

It has also become valuable to the engineers for their own direct use. Formerly the corrosion engineer was the only one who could successfully locate information. It takes no more time to fill out these cards than it did the old ones, and it has been noted that their greater usefulness is an incentive for more consistent recording of corrosion data.

All in all, punched cards have transformed a crippled file into a serviceable one. The number of frustrated corrosion file searches has been greatly reduced.

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3. Carwardine, J. E. D., "A Punched-Card System," *Chemistry in Canada*, 9, pp. 36-8 (1950).
4. Casey, R. S. and J. W. Perry, "Punched Cards, Their Applications to Science and Industry," Reinhold Publishing Corp., New York (1951).
5. Perry, J. W. Kent, A. and M. M. Berry, "Machine Literature Searching," Western Reserve Univ. Press, Interscience Publishers, New York (1956).

New Data on Plastic Pipe Reported

The plastic pipe and fittings industry has been fortunate in having the steel industry enter into the production of plastic products. Steel companies have brought with them extensive research facilities, and experience.

Long term physical data, gathered by one company, covering 15,000 hrs. of continuous testing at temperatures up to 150 F., disclose the following as reported at the 13th Annual Conference of the National Association of Corrosion Engineers in St. Louis:

• Normal impact PVC* pipe withstands from 10-30 times greater creep than high impact PVC pipe, before rupture, when subjected to identical pressure and temperature conditions.

• Failures of high impact PVC pipe under hydrostatic pressure tests are generally along weak "knit" lines. These lines are produced during flow of the plastic around the mandrel in extrusion. Normal impact pipe does not present this difficulty.

• Cemented socket-type fittings are stronger and less susceptible to failure than threaded fittings. This is true under high stress, excessive vibration, abnormal flexure, and elevated internal pressures. Threaded pipe fittings introduce notch sensitivity.

• Hot gas welding of plastics differs from metals in that complete fusion is not obtained. Plastic welding involves the same type of weld joint preparation, as metal welding. And the filler rod is composed of material identical to the parent sheet or stock to be welded. Filler rod and surfaces are heated with a direct blast of hot air which only melts the surfaces to be bonded. The weld bead is put down with hand pressure and allowed to cool.

• Unplasticized polyvinyl chloride parts can be joined with cements. About 10 to 15 parts of PVC is dissolved in solvent—cyclohexanone or tetrahydrofuran. This cement is worked into the interfaces of the pieces to be joined. When both surfaces are tacky, the two pieces are clamped together until the solvent has evaporated or migrated.

* Also referred to as Type I PVC. This is substantially pure PVC resin containing a minimum amount of stabilizer. High impact PVC, or Type II, contains modifying resins, fillers, and small amounts of plasticizer. Type II has a higher impact strength, but otherwise lower physical and mechanical properties than Type I or normal impact PVC.

New Ductile Iron Announced

A variation of the recently developed family of ductile cast irons is now in production at American Meter Co.'s Reliance foundry in Alhambra, Calif. It's claimed to have iron's low melting point, good fluidity, castability and machinability, and steel's high strength, toughness, ductility and wear resistance. It can be used in the production of intricately shaped castings, and for castings subjected to severe service conditions, such as bending and twisting.

Called Relianite, it comes in four grades: R1 offers toughness, shock resistance and maximum machinability; R2 for heavy-duty machine parts; R3 for wear resistance; and R4 for high temperature applications up to 1,600 F.

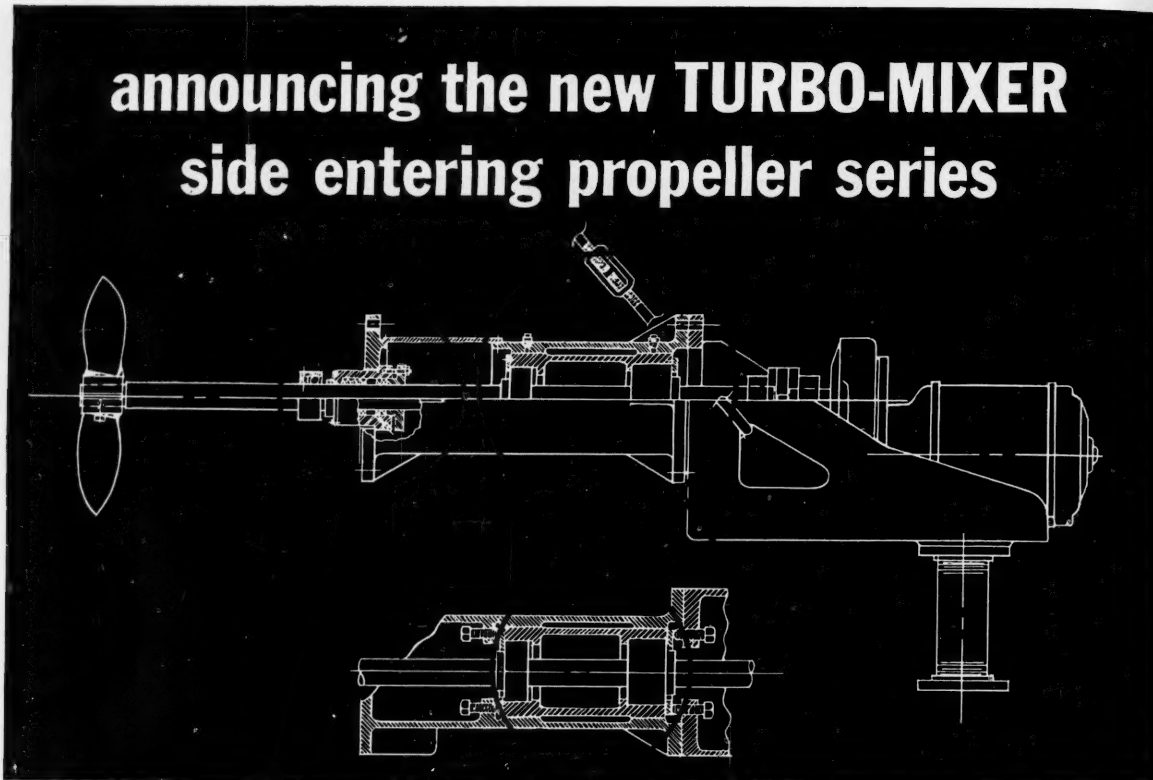
Chemical Engineering

People

JUNE 1957

Department Index

announcing the new TURBO-MIXER side entering propeller series



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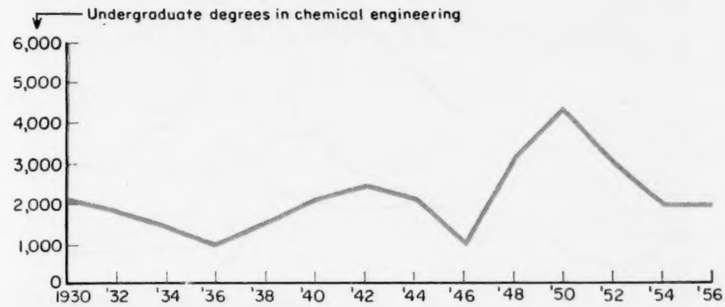
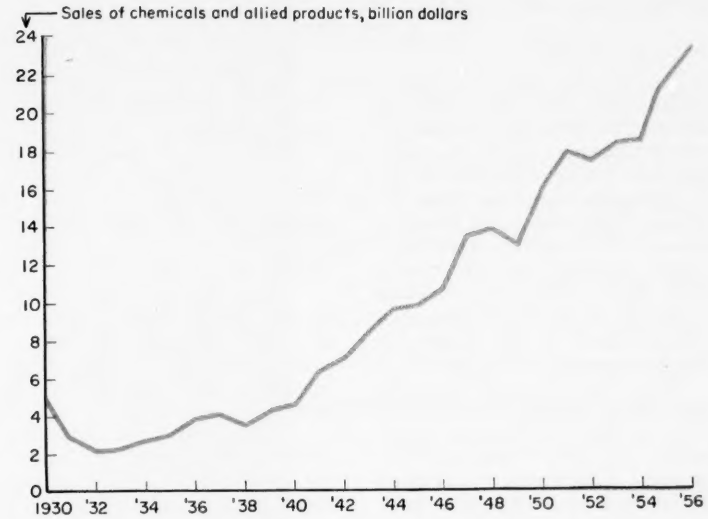


And a Phenomenal Rise in Chemical Manufacturing



How Easily Can You Be Replaced?

Although there are more engineering students this year, chemical engineering enrollments continue to lose ground. Take a look at your future competitors.

As a working engineer you represent a commodity of considerable value to your employer. He has a sizable investment in the expense of recruiting and training you for your present job. This investment may or may not have been recovered with an adequate return.

On the negative side of the ledger he must write you off as an expense item while he keeps you and your family housed, clothed and fed; and while he keeps a desk in front of you and a plant or office roof over your head.

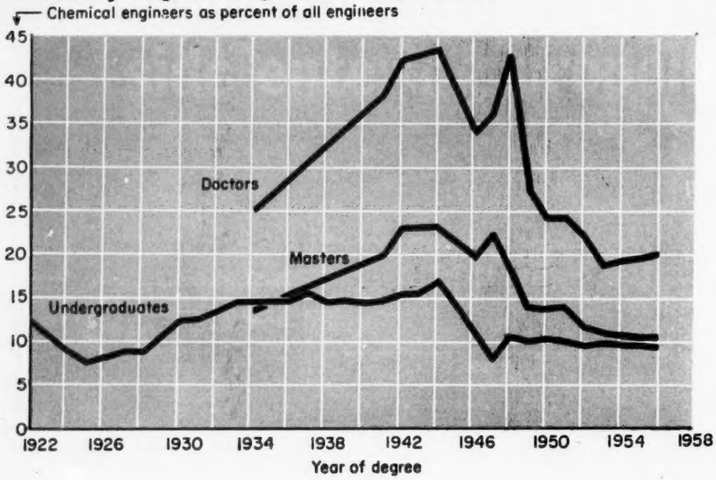
But your most positive value to your employer is the availability of your engineering services when he requires them. In reality, he pays you for the immediate availability of your services.

When You're Not Available

If you were not available—or when your desk is piled sky high with projects that you don't have time to get to—your employer would have to look elsewhere for engineering services.

And this he does. He goes out into the open marketplace and tries to secure the services of other engineers. Of course there are many places that he can do this. Often he turns to the college campus and looks at the new

How Many Engineering Grads Are Ch. E.'s ?



graduates. At Northwestern Univ., for example, a total of 520 companies came to the campus last spring with jobs to fill.

Engineers were in greatest demand. They will be in greatest demand this spring with companies looking for 35% more than they got last year.* Each engineer or new graduate who offers himself to this market becomes a competitor to you.

When they are many competitive sellers of engineering services in the marketplace, your value to your employer decreases. That's why you'll want to take a long hard look at your competition from the standpoint of both quantity and quality.

They'll Be Fewer In Number

We'll tackle the quantity question first, because the figures (for new graduates, at least) are now readily available.

With the cooperation of and a grant from the Thomas Alva Edison Foundation, New York University Press has just published a book on the subject of engineering enrollment, edited by Norman N. Barish.†

Barish, professor and chairman of industrial and management engineering at NYU, supplies the answers to these important engineering manpower problems:

- How rapidly have we been training engineers in the past? What is the rate of growth of engineering enrollments and graduations? What kinds of engineers are we training?
- How has the rapid budding of new engineering specialties affected the popularity of the older branches? Is large-scale enrollment in graduate study here to stay?
- What's the attrition rate of engineering students? What's the future outlook for enrollments and successful graduations?

What About Chemical Engineers?

While many of you are interested in discussion of these engineering manpower problems, almost all of you are especially interested in specific answers to these questions for chemical engineers alone.

Barish, as editor, provides this information in a chapter written by Thomas H. Chilton, technical director of the engineering department at the DuPont Co. We quote from Chapter X (see also the chart on this page):

"The most noteworthy feature of the curve of chemical engineering enrollments—overlooking the dislocations caused by World War II and the postwar return of students under the G. I. bill—is the shift in the percentage of all undergraduate chemical engineering enrollments from 10% in the 1920's to a continued 15% during the 1930's, and since 1945 back to just under 10%. Even numerically, total chemical engineering undergraduate enrollment in the current year, 1955-56, is lower than it was in the last prewar year, 1942-43, and the same holds for the freshman class as well."

"Can this falling off in chemical engineering enrollments be due to any slackening of demand or opportunities for chemical engineers? The figures cited earlier do not support any such conclusion. It can only be that in the general shortage of engineers, the newer fields of electronics and the manufacture of automobiles and appliances have greater appeal for the undergraduate."

Actual Numerical Decrease

Our yearly output of chemical engineering graduates now hovers around the 2,000 mark, as shown by the chart on the previous page. Not only are chemical engineers losing ground percentagewise in the enrollment race, but also the actual number of graduates each year seems to have trouble just keeping up to the level of the previous year.

Thus we can see that the supply of new chemical engineers entering our profession each year is almost a fixed number. If supply and demand for engineers followed simple "perfect-market" theory, we could make a flat prediction that the price of engineering will be driven upward.

However, managerial economists would stop us with words such as demand analysis, inelasticity of the market, imperfect market conditions, lack of competition, etc. But we can say this without fear of contradiction:

Demand for chemical engineering services is increasing at a rate that is not satisfied by the services that can be supplied by only 2,000 new graduates each year. Therefore, those now in the profession will become more and more valuable to their employers each year until the supply picture changes.

---

* *Business Week*, Jan. 26, 1957, p. 145.

† Barish, N. N., Editor, "Engineering Enrollment in the United States," New York University Press, Inc., New York (1957), 226 pp., $7.50.

Next Month: The Fine Art of Changing Jobs

Now in preparation is a two-part series of You & Your Job feature stories that you may never need, because some of you will never again be looking for a job. But for those of you who will actively pursue new employment at least once before you retire, these two features will be a valuable information package. First, some timely tips on the art of changing jobs, written by a chemical engineer who just has. Then, look before you leap, what will it cost to change your job?

Until the trend is reversed by booming population or a hurried swing to recruiting talent into our engineering schools, you might almost be considered a member of a diminishing horde.

How Good Is Your Competition?

In chemical engineering—as in many other academic disciplines—we know that we can't match number for number. One warm body is not as good as another. There is an element of quality that must be considered in any accounting.

How good is your competition?

Pretty good, but not good enough, is the opinion of one of our largest oil companies. Standard Oil Co. (N. J.) reported this attitude last fall to a symposium on "Does Present Chemical Engineering Education Meet Modern Industrial Needs?" Jersey Standard reported that their young engineers (test sample consisted of 125 recent graduates and their supervisors) are strongest in their knowledge of chemical engineering fundamentals, calculation methods and professional ethics.

They are weakest in communication—both oral and written—and in engineering judgment.

How to Meet It

Armed with this information you can now consider what you can do to meet this quality of competition.

Several years ago we became intrigued with a book by the famous humorist Stephen Potter. He called it "One-Upmanship." The book describes the fine art of how to get one up on the other fellow.

If we were in a humorous mood we might consider some of Potter's suggestions and apply them to getting one up on the new graduates. But competition can be a serious thing. Let's restrict ourselves to these few suggestions:

- Consider what you might do to brush up on *your* fundamentals. The technology of a given industry can be imparted to a man after he goes to work in that industry, whereas it is seldom that he can compensate for deficiencies in fundamentals, particularly in keen technical competition.
- Do *you* have a professional attitude?
- In all engineering work, communication is an especially critical requirement. Can you speak and write effectively? Do your superiors hate to read your technical reports? Do you manage to get across what you really mean in what you say and write?
- It may be argued that engineering judgment is acquired only through years of experience. In some matters this is true. In others, a man can exercise good judgment early in —and throughout—his career. How do you rate?

What the Future Holds

What we have suggested above will give you some clues about what you can do to face today's competition more effectively. That may be quite an assignment in itself. But there's more to consider than the class of June 1957.

Last September 77,738 students enrolled in freshman engineering courses. Engineering Manpower Commission of EJC predicts that 57% of these freshmen will get to graduation exercises in 1960.

Although we have no way of knowing at this early date, this may mean that there will be twice as many chemical engineering graduates in 1960 than there were in 1956. In quality the 1960 graduate will be even better than his 1957 counterpart.

If suggested changes in chemical engineering curricula are adopted in time, the 1960 B. S. may have been exposed to:

- Courses in statistical theory and familiarity with electronic computer information.
- Integration of the teaching of chemical engineering thermodynamics with teaching of physical chemistry and of reaction kinetics. Emphasis will be on teaching of fundamentals in a coherent pattern.
- General reduction in the emphasis on qualitative and quantitative chemistry courses. More time will be available for chemical engineering subjects.
- Engineering drawing, like surveying, will begin to vanish from the chemical engineering curriculum. (In industry the new graduate will find draftsmen and tracers to do his engineering drawing for him.) Again, more time will be made available for chemical engineering subjects.
- Use of more industrial problems as classroom teaching aids will prepare the 1960 graduate for a faster transition from the school to the industrial situation.

You and 1960

All this adds up to the possibility that the graduates of the future will be better prepared to offer your employer engineering services that will be worth more to him.

If for no other reason, this intensifies the pressure upon you to nurture your professional development year by year. Don't let yourself fall by the wayside.

Do you have a definite program designed to further your professional progress? If not, it's never too late to get started. Consider the 1960 graduate.

Will he be one up on you?

SEMANTIC BARRIERS

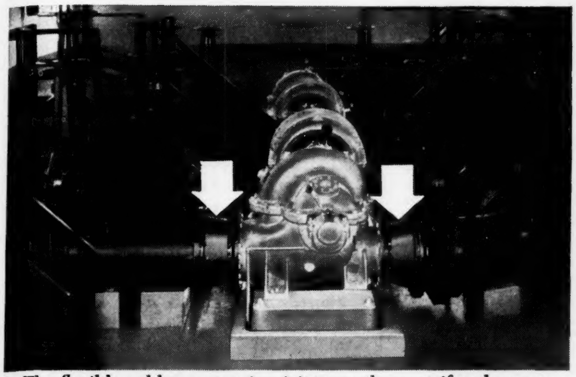
. . . Can Be Broken

Today's manager lives in increasingly complicated network of communication, with lines leading up, down and sideways from his desk. He has to keep

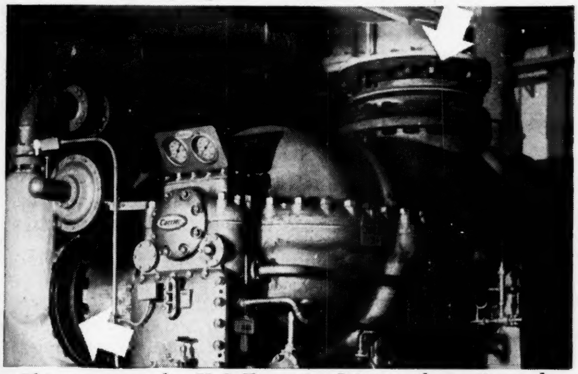
US RUBBER

EXPANSION JOINTS

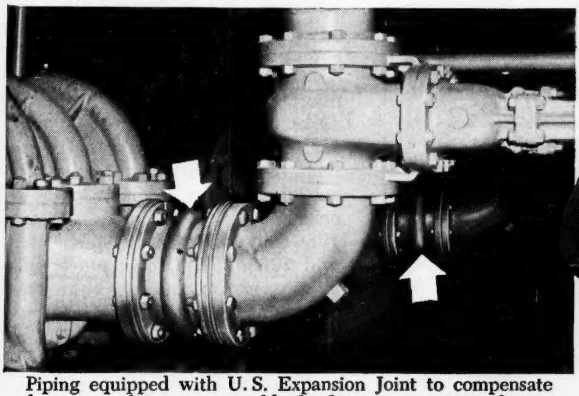
Expanding the Designer's Scope



The flexible rubber expansion joints on the centrifugal pump installations (above) are made by U. S. Rubber. They prevent stresses caused by expansion and contraction.



This compressor has U. S. Expansion Joints on the suction and discharge lines. Like all U. S. Joints, these insulate against the transfer of vibration and noise.



Piping equipped with U. S. Expansion Joint to compensate for any misalignment caused by load stresses, wearing of parts or settling of building.

U. S. Rubber Expansion Joints are resilient and therefore do not, like metal, set permanently when compressed. Constant flexing merely keeps them alive... prevents brittleness.

- They absorb both axial and lateral deflection far more than metal joints. Greater insulation against vibration and pump noises. No electrolysis, corrosion or erosion.
- Handle pressures from 40 lbs. to 125 lbs.
- The outside diameter of the arch is smaller than on metal joints. (Face-to-face dimensions, even with multiple arches, are smaller.)
- Weight is much less. This, plus the fact that no gasket is needed between flanges (metal joints require gaskets) results in an easier installation lowering the cost.

"U. S." was the *first* to develop expansion joints. They are at work in every kind of industry, prolonging the life of equipment in pressure or vacuum pipe systems. Some are still in service, after 30 years of operation. Obtainable at any of the 28 "U. S." District Sales Offices, or write us at Rockefeller Center, New York 20, N. Y. In Canada, Dominion Rubber Co., Ltd.

For the complete technical information catalogue on the entire line of U. S. Rubber Expansion Joints, contact your nearest "U. S." District Sales Office or write us at Rockefeller Center, New York 20, New York.

US RUBBER

Mechanical Goods Division

United States Rubber

lines clear, not only to those below in the business hierarchy, but to whatever levels may be above.

In an article written for American Management Assn.'s *Management Review* (April 1957, p. 58), Stuart Chase tells how to identify the six most common roadblocks on the communication line. They are:

- Confusion of words with things. Words are so cardinal in human affairs that we tend to assume that behind every word must stand a physical thing to which the word refers.
- Careless use of abstract words.
- Confusion of facts with personal opinions.
- Judging events and people in terms of black or white. The bell-shaped frequency distribution curve is a useful offset to this potential roadblock.
- False identity based on words.
- Gobbledegook. (And this includes technical jargon.)

Chase suggests that semantics is no monopoly of heavy thinkers. It is for anyone to use who needs to keep his communication lines clear.

WANTED

. . . *Research Engineers*

Included in the recently released McGraw-Hill survey of business' plans for new plants and equipment—1957-1960, is some estimate of our future industrial demands for research manpower.

As part of the survey, manufacturers were asked to estimate how much expenditures for research and development will increase (or decrease) between 1956 and 1957 and between 1957 and 1960. Then, how much will this program change your employment of scientists and engineers in research and development?

Manufacturing companies estimate that they will need 7% more scientists and engineers in 1957. And they expect to employ an additional 15% by 1960.

Note that, as used in this survey, research and development includes basic and applied research and engineering, and also

design and development of prototypes and processes.

Largest increase in scientific and engineering employment, for the four-year period, is expected in petroleum refining (33%). Next comes the steel and machinery industries (32%) and electrical machinery (29%).

Chemical manufacturers want 5% more researchers in 1957 than in 1956; and 16% more between 1957 and 1960.

ENGINEERING SCHOOL

. . . Will Add Chemical

Charles E. Wilson, former president of General Electric Co., will head up Manhattan College's (Riverdale, N. Y.) brain trust in education.

To be known officially as Manhattan College's Council on Engineering Affairs, this group of industry leaders will help direct the programing of engineering education at the college.

Within a few years, Manhattan college plans to add degrees in nuclear engineering, administrative engineering and chemical engineering to its present list of civil, electrical and mechanical.

Part of the plan is the construction of a new engineering center on campus to be financed by donations of $4,000,000 for facilities and faculty.

NEW PLAN

. . . to Broaden Engineers

Diamond Alkali has launched an intensive, 18-month "engineering experience - technical training program" designed to broaden the advancement opportunities of newly employed chemical engineering graduates.

Thornton F. Holder, director of research at Diamond's Painesville, Ohio research center has appointed R. L. Annis as program supervisor.

Under the plan, each engineer assigned will work for 18 months in three different assignments of six months' duration. Selection of assignments is based on the judgment of the program supervisor, keeping in mind the employee's work preference as well as those of the work group involved.

PEOPLE . . .
TECHNICAL

Best 500 Between Boards

TEXTBOOK OF POLYMER CHEMISTRY. By Fred W. Billmeyer, Jr. Interscience Publishers. New York. 518 pages. $10.50.

Reviewed by D. F. Othmer.

This is a very useful book which combines, in an extremely successful manner, the promulgation of fundamental knowledge with the communication of factual details.

It is a survey of a broad subject with many ramifications and, as such, is an admirable survey or text, rather than a comprehensive treatise.

For the practicing chemical engineer interested in operations related to the field, rather than devoted to expanding the field through intensive study and research, it probably is the best 500 pages between boards for ready reference.

After a short introductory chapter, the author presents a clear and comprehensive picture of the structure and behavior of macromolecules, enumerates briefly but succinctly the experimental methods for the study of polymeric systems in solution and bulk and describes the essential conclusions drawn from the results of these studies. The random-coil concept, with all its consequences, is put forward as the basis of our understanding of structure-property relationships.

The next chapter deals with the various methods of polymer synthesis in a modern quantitative manner, clearly pointing out the principles but, at the same time, presenting a wealth of experimental data in well-designed graphs and carefully assembled tables. It is a very readable and instructive chapter.

Then follow three chapters describing in a more specialized manner the particular structure and behavior of those materials which are specifically useful as plastics, fibers and rubbers re-

BOOKSHELF

EDITED BY J. B. BACON

spectively. Also, this part of the book has an abundance of data, diagrams and graphs representing the present state of the art.

Billmeyer's book will be equally valuable and indispensable as the first text for research chemists who attempt to discover new species of polymers, and as a guide for the engineer who wants to apply intelligently the types already existing.

Solid State for Novitiates

THE DEFECT SOLID STATE. By T. J. Gray, D. P. Detwiler, D. E. Rase, W. G. Lawrence, R. R. West and T. J. Jennings. Interscience Publishers, New York. 511 pages. $11.

Here's a book you'll find worth while if you want to keep abreast of some of the recent trends in engineering—ideas that are now moving into industry in a big way.

With growing emphasis on industrial possibilities of catalysis, corrosion and high-temperature phenomena, intermetallic compounds and semiconductors, there has come a need for a book to guide novitiates in a tour of the far-reaching areas of solid-state theory and applications.

For chemical engineers, the book will help fill that need. The volume presents a clear, not-too-difficult introduction to the concepts, applications and literature (via valuable, extensive references) of the solid state. Chapters on semiconductivity, reactions in the solid state, corrosion processes, defect structure and catalysis, phase equilibria, ceeramic materials for high temperatures and intermetallic compounds will be especially interesting. And the reader will find instructive, too, the chapters on diffusion in ionic lattices, sintering, magnetic properties of solids and dielectric properties.

Treatment of subjects throughout the book is highly generalized; the expert in a particular

field will find that specialized considerations frequently have been omitted and theoretical treatment cut to a minimum. Most of the book presumes not more than a passing familiarity with electricity, magnetism and atomic physics.—JBB

How Many Engineers?

ENGINEERING ENROLLMENT IN THE UNITED STATES. Edited by N. N. Barish. New York University Press, New York. 226 pages. $7.50.

With the cooperation of, and a grant from, the Thomas Alva Edison Foundation, New York University Press has just published this authoritative volume on the subject of engineering enrollment.

Norman Barish, professor and chairman of industrial and management engineering at NYU, serves as editor and supplies the answers to these important engineering manpower problems:

- How rapidly have we been training engineers in the past? What is the rate of growth of engineering enrollments and graduations? What kinds of engineers are we training?
- How has the rapid budding of new engineering specialties affected the popularity of the older branches? Is large-scale enrollment in graduate programs here to stay?
- What's the attrition rate of engineering students? What's the future outlook for enrollments and successful graduations?

While all the branches of engineering are covered in this reference, the chapter on chemical engineering written by Thomas H. Chilton, technical director of Du Pont's engineering department, will interest you most.

For further discussion see this month's You & Your Job.—RFF

BRIEFLY NOTED

ANALYSIS FOR PRODUCTION MANAGEMENT. 503 pp. *By Edward H. Bowman and Robert B. Fetter. Richard D. Irwin, Inc.* $7.80. Should be helpful to the

man in industrial engineering. Contains chapters on schematic models, linear and special programming, statistical control, sampling inspection, industrial experimentation and ten case studies.

ANNOTATED BIBLIOGRAPHY OF LITERATURE AND PATENTS RELATING TO PRODUCTION OF CARBON BY DECOMPOSITION OF CARBON MONOXIDE. 39 *pp. By H. Jack Donald. Available free. Mellon Institute*, 4400 *Fifth Ave., Pittsburgh* 13, *Pa.* Gives abstracts from the literature through 1952.

ANNUAL REPORT FOR 1955 FOR THE EUROPEAN FEDERATION OF CHEMICAL ENGINEERING. 150 *pp. DM* 10. ANNUAL REPORT FOR 1955 FOR THE EUROPEAN FEDERATION OF CORROSION. 54 *pp. DM* 10. *Frankfurt Office of the General Secretariat, European Federation of Chemical Engineering* (or *Corrosion*), *Frankfurt am Main* 7, *Postfach.* Summarizes work and activities of various technical groups up to the end of 1955.

THE CHEMICAL INDUSTRY FACTS BOOK. 160 *pp. Manufacturing Chemists' Association*, 1625 *Eye St., N. W., Washington* 6, *D. C.* $1.25. Gives information on development and function of chemical industry.

CHEMICAL PRODUCTION FLOWSHEETS, PLANT DIAGRAMS. 40 *sheets. Dechema, Deutsche Gesellschaft fuer chemisches Apparatewesen, Frankfurt am Main* 7, *Postfach. DM* 16. Contains 220 diagrams representing types of equipment most commonly used in chemical technology.

HANDBOOK OF SOLVENTS—VOL. I PURE HYDROCARBONS. *By Ibert Mellan.* 249 *pp.* $6.50. *Reinhold Publishing Corp.* Lists hydrocarbon solvents by trade name, classified according to distillation range; gives chemical composition, evaporation rate and other properties.

THIRD TECHNICAL PROGRESS REPORT—AIR POLLUTION FOUN-

DATION. 110 *pp.* $3. *Air Pollution Foundation,* 704 *S. Spring St., Los Angeles* 14, *Calif.* Summarizes technical details of work done in fields of atmospheric physics and chemistry and on auto exhausts and incinerators.

DISPOSAL OF INDUSTRIAL WASTE MATERIALS. 157 *pp. Papers from symposium of Society of the Chemical Industry conference at Sheffield University, April* 17-19, 1956. *Macmillan Co.* $7.50. Includes useful information on waste treatment in pharmaceutical, pesticide, leather, rubber, textile, fiber, ceramic, petroleum and atomic industries, and on ore-dressing wastes and sulfur recovery.

MANUAL ON INDUSTRIAL WATER. 502 *pp. American Society for Testing Materials,* 1916 *Race St., Philadelphia* 3, *Pa.* $6. Contains a complete appendix in addition to a comprehensive discussion of water, its uses, treatment, sampling, analysis and difficulties caused by it.

SYMPOSIUM ON PROPERTIES, TESTS AND PERFORMANCE OF ELECTRODEPOSITED METALLIC COATINGS 129 *pp. American Society for Testing Materials,* 1916 *Race St., Philadelphia* 3, *Pa.* $3. Presents information on cleaning, corrosion behavior and evaluation of electrodeposited metallic coatings.

TECHNICAL DATA ON PLASTICS 224 *pp. Manufacturing Chemists' Association,* 1625 *Eye St., N. W., Washington* 6, *D. C.* $3.25. Presents graphical and tabular data on fabrication, durability, electrical, mechanical and miscellaneous properties of 25 types of plastic materials.

THERMODYNAMIC PROPERTIES OF CHLORINE. 39 *pp. By R. M. Kapoor and Joseph J. Martin. University of Michigan Press, Ann Arbor, Mich.* Gives properties of superheated vapor, saturated vapor and liquid, pressure-enthalpy and temperature-entropy diagram of chlorine. Presents development of equations and method of calculating tables.

THERMODYNAMICS AND STATISTICAL MECHANICS. 495 *pp. By A. H. Wilson. New York: Cambridge University Press, New York.* $9.75. Advanced treatment, fairly heavy on the math; primarily for physicists, but enlightening for the engineer. Gives applications of thermodynamics to ideal and nonideal gases and solutions and to solids.

TRILLINEAR CHART OF NUCLIDES, *2nd ed. Compiled by William H. Sullivan. Superintendent of Documents, U. S. Government Printing Office, Washington* 25, *D. C.* $2. Shows up-to-date nuclear data.

MORE NEW BOOKS

AMERICAN INSTITUTE OF PHYSICS HANDBOOK, 1st ed. Coordinating Editor, Dwight E. Gray. McGraw-Hill. $15.

AUTOMATION IN BUSINESS AND INDUSTRY. Edited by Eugene M. Grabbe. Wiley. $10.

AUTOMATION: ITS PURPOSE & FUTURE. By Magnus Pyke. Philosophical Library. $10.

BUILDING AN ENGINEERING CAREER. By Clement C. Williams and Erich A. Farber. McGraw-Hill. $4.75.

ELECTRICITY AND MAGNETISM. By J. Newton. Philosophical Library. $10.

ENGINEERING THERMODYNAMICS. By C. Osborn Mackey, William N. Barnard and Frank O. Ellenwood. Wiley. $7.95.

HANDBOOK OF HARD METALS. By W. Dawihl. Philosophical Library. $10.

HUMAN RELATIONS IN BUSINESS. By Keith Davis. McGraw-Hill. $6.50.

INDEXES TO PUBLICATIONS OF THE AMERICAN CERAMIC SOCIETY. Published by the American Ceramic Society. $5.

INSTRUMENTAL ANALYSIS. By Paul Delahay. Macmillan. $7.90.

PEOPLE . . .

MEET YOUR

Raymond Byler

CHEMICALS USED IN MINERAL PROCESSING. P. 200.

Author Raymond Byler received his B. S. degree at the University of California's College of Mining & Metallurgy in 1924, and he's been active in the same field ever since.

Professional experience includes many years in the metallurgical and chemical process fields, in areas running the gamut from research to actual operations, from processes to equipment. Much of his employment has taken place right here in the States though he has worked in foreign countries, particularly Mexico and Canada.

Spelled out, his work record looks like this: He joined Arthur D. Little's San Francisco office in 1954 with an assignment involving the economic and technical evaluation of mineral resources and processing industries.

Before that, he had been vice president in charge of engineering and research for The Merrill Co. During the war he chief engineered the design and erection of a plant for producing aluminum powder for incendiary bombs and depth bombs. At that time, he was also in charge of process development and plant design for Metals, Inc., where work was geared toward the production of pyrophoric metal powder for the Chemical Warfare Service.

Byler served as chairman of the mining branch of the American Institute of Mining & Metal-

AUTHORS

M. A. GIBBONS

lurgical Engineers in 1953. Currently, he is director of the executive committee of the Society of Mining Engineers.

He also holds membership in the American Chemical Society, the Mining & Metallurgical Society of America, the Engineers' Club, the mining committee of the San Francisco Chamber of Commerce, and the American Institute of Mining, Metallurgical & Petroleum Engineers.

Donald E. Garrett

"ORGANIZE CORROSION DATA." P. 342.

Since he first joined American Potash & Chemical Corp., two years ago, Donald Garrett has been closely associated with the company's corrosion department at the Trona, Calif., plant.

Garrett tells us that whenever he wanted to get any information out of the extensive corrosion files available at Trona, he was constantly frustrated by the lack of a simple cross filing and indexing system. He was sure that there should be some easier method than the one in use.

A punch card technique was devised and proved to be just what the plant needed. His hope to "spare the patience and tempers of contemporaries in a similar predicament" resulted in the present article.

A native of California, Garrett studied on home grounds at Berkeley's University of California. Later, he earned a Ph.D. at Ohio State.

AUTHORS . . .

Since 1950, though, Garrett has been back working on home soil. Of the last seven years, he has spent two years with Dow Chemical Co. in Pittsburgh, Calif.; three years with Union Oil Co., at Wilmington and Brea, Calif.; and the past two years with American Potash & Chemical Corp.

At present, he is manager of research for the latter firm at its Trona, Calif., plant.

Frank O. Osmon, Jr.

"ORGANIZE CORROSION DATA. P. 342.

Last year, Frank Osmon spent his summer vacation from school working for American Potash & Chemical in Trona, Calif.

Under the direction of Coauthor Garrett, who is manager of research at Trona, Osmon transferred information from an obsolete file on corrosion data to a punched card system. The system proved so worthwhile that the two men decided to share their wealth—in the current article.

Osmon is due to get his degree in chemical engineering by January 1958 at the University of Texas. At the school, he is active in the student branch of the AIChE. He has also taken on work as a grader in the Math department during the past two years.

Last summer, Osmon's duties at American Potash were those of a student trainee in the research department. The year before, he worked as a helper at the firm's bromine, lithium carbonate plant.

Osmon lives in Austin, Tex. Among "outside" interests, he lists photography.

Charles F. Gerlach

ECONOMICS: CHLORINE-CAUSTIC OUTLOOK. P. 200.

Wyandotte Chemicals' Charles F. Gerlach has been associated with the firm since 1951.

His familiarity with the economics of the chlorine-caustic horizon comes largely as a result of his responsibilities for the sales and promotional programs for all of Wyandotte's inorganic chemicals.

Gerlach has a broad and varied educational background. He earned a B. A. in 1936 from the University of Wisconsin and stayed on to work for an M. S. in entomology and chemistry.

During World War II, he served the U. S. Public Health Service, Communicable Disease Div., with a rank of captain.

Before coming to Wyandotte, he had been vice president and general sales manger of Michigan Chemical Corp.

Robert I. Chien

ECONOMICS: CHLORINE-CAUSTIC OUTLOOK. P. 200.

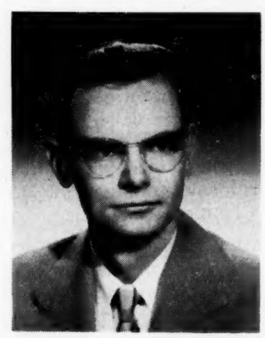
A native of China, Robert I. Chien earned an LL.B. degree there before he came to the

United States. Since that time, he has added an M.B.A. from the University of Denver, a master's in statistics as well as a Ph.D. in economics from the University of Minnesota.

Chien was an instructor of economics and statistics at the University of Minnesota until 1951 when he joined Wyandotte Chemicals Corp. as a senior market research and statistical analyst. Currently, he is manager of market research for Wyandotte' Michigan Alkali Division.

At present, Chien is also president of the Detroit Chapter of the American Statistical Assn. and program chairman of the American Marketing Assn. in Detroit.

Chien holds active membership in the Chemical Market Research Association, the advisory council of marketing research directors of the National Industrial Conference Board, and the American Society for Quality Control.



Robert C. Green

REDUCE COSTS WITH SCALE MODELS. P. 235.

Like Co-author Stanley Shukis, Robert Green was still assigned to the Army's Chemical Corps Engineering Command in Maryland when he helped prepare the current article.

Green went in under the Army's Enlisted Scientific and Professional Personnel program as a chemical engineer. He, too, was engaged in the design of plants for the production of chemicals.

Just now, though, he's busy earning a master's in chemical engineering at Ohio State University. Specifically, he's study-

ing, under Dr. Webster B. Kay, the effect of structural isomerism on the heat capacities of fluorinated hydrocarbons.

This Fall, when he completes work at Ohio State, Green will join Esso Research & Engineering in Linden, N. J., in their chemicals development division.

Before his stint in the Army, Bob Green was employed by Herrick L. Johnston, Inc., Columbus, Ohio, as a cyrogenic engineer in the production of liquefied gases. He did undergraduate work at the University of California in Los Angeles.

Outside the office, Green likes to enjoy an occasional game of bridge or golf. And, when he manages to get back to his native California, he heads for the streams of the High Sierras to fish for trout.

And, when he took leave of the school, in June 1953, he graduated first in the engineering class.

While at UCLA, Green was a member of Tau Beta Pi and Phi Eta Sigma honorary fraternities.

Stanley P. Shukis

REDUCE COSTS WITH SCALE MODELS. P. 235.

To someone who spends a good bit of spare time boning up on developments in creative engineering, using scale models in plant design came as a natural course of events.

Do-it-yourself-hobbyist Stanley P. Shukis found it so and now the Army Chemical Corps' Engineering Command is sharing his enthusiasm.

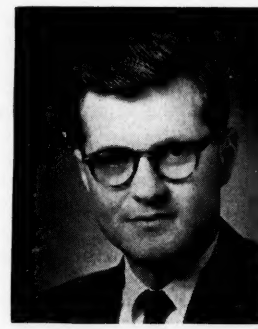
Shukis went to work for the Command (then an Agency) in 1954 where he directed the piloting of a new process for producing bleaching powder. He was

AUTHORS . . .

also project engineer on five plant designs and in charge of the Corps first two attempts to use the scale models as aids in design. In 1945, he was awarded the bronze star award.

Other interests include photography, stills as well as movies. Shukis is also reasonably fluent in German and Lithuanian. In fact, he did some translating for the Government during the war.

Recently, Shukis bought a new ranch home in Aberdeen, Md.



Leonard M. Naphtali

NEW STATISTICAL METHOD RAPIDLY DETERMINES OPTIMUM PROCESS CONDITION. P. 238.

Brooklyn Poly's Associate Professor Leonard M. Naphtali has a tough but never dull schedule what with teaching, research and consulting projects.

His main interests are in the area of chemical engineering science but he keeps tabs on the other sciences, too, as a hobby. Beyond that, he's a "hi-fi" enthusiast, makes his own furniture and enjoys "conversation on any conceivable subject and on many inconceivable ones too."

Before coming to Brooklyn Poly, Naphtali worked at Ford Motor Co.'s scientific lab. He was employed in the metallurgy department as a research engineer, working on iron ore reduction with fluidized beds.

Naphtali did undergraduate work in chemical engineering, in his native New York City, at Cooper Union. He earned his master's and doctorate at the University of Michigan.

Sidney I. Neuwirth

NEW STATISTICAL METHOD RAPIDLY DETERMINES OPTIMUM PROCESS CONDITION. P. 238.

Like Co-author Naphtali, Sidney Neuwirth was born and educated in New York City. Neuwirth attended New York University, where he took on a B. S. and a master's in mathematical statistics and minored in chemistry and biology. His dissertation was on the subject of "Maximum Likelihood."

Since then, he has divided his time between studying for a doctorate in the same field and working as a research statistician. For the Ph.D., he has been taking courses at Columbia University and attended the University of Chicago for a time. In industry, he has been employed as chief research statistician for Schering Corp., Bloomfield, N. J., and the American Medical Assn., Chicago. He has also done some independent consulting work as a statistician.

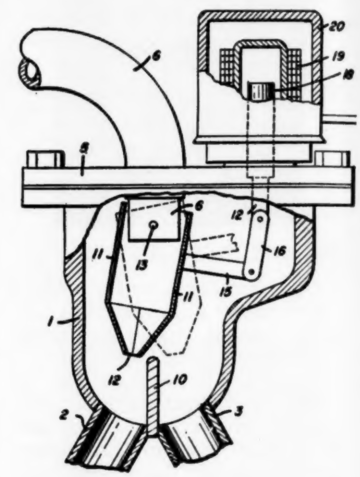
In the past, Neuwirth has authored other articles. In April 1954, his "Statistics—Guide and Guardian" appeared in the *Monthly Bulletin.* A year later, he published his "Use of Statistics as an Important Tool in Research" in the *Industrial Laboratories'* May issue.

At present, Neuwirth is an active member of the American Society for Quality Control, metropolitan section. He is also a member of the New York Academy of Sciences, the Operations Research Society, the American Mathematical Society and the AAAS.

Sid lists bridge and tennis among his foremost hobbies, though his two children come first as a spare time demand.

PEOPLE . . .

LETTERS:



Con: Patent Infringement

Sir:

I have read your Plant Notebook item, "New Reflux Splitter Resists Corrosion," by L. T. Haire and S. R. Eckhaus, as it appears in your December 1956 issue (p. 220).

The device as described in this article is covered by our patent (U. S. 2,518,574), with other claims pending. The authors of the article have conflicted with our interests in building such an apparatus without our permission and in instructing others to do likewise.

Automatic reflux splitters of the type described are manufactured by us and distributed on a nationwide basis.

P. N. HEERE
Distillation Engineering Co.
Livingston, N. J.

Not Yet, Anyway

Sir:

You have done an excellent job with the April cover and the article on "How to Check Equipment Quality" (pp. 261-266).

However, there is an error in the biography of the author (pp. 331-332). Mr. Veith's title is chief inspector, not chief engineer.

F. C. BREUNINGER
E. I. du Pont de Nemours & Co.
Wilmington, Del.

PRO & CON

C. H. CHILTON

Better Estimating Methods

Sir:

Your editorial on the need for more cost data (April 1957, p. 3) was interesting, and I wish you luck on obtaining additional data.

You say that no more is needed on "estimating methods." I think you must refer chiefly to methods of fixed capital cost estimation, and I agree that enough has been written on this subject. This is also the chief area where very little recent data have been published on a correlated basis.

However, methods of estimating working capital and direct manufacturing costs (particularly their overheads) are, I think, neglected in the literature, and much more needs to be published on them. Also, I feel that more needs to be published on methods for profitability determination after all the forecasts have been made.

JAMES B. WEAVER
Atlas Powder Co.
Wilmington, Del.

▶ *Look for articles now in preparation which will deal with belt conveyor costs, piping costs and evaluation of capital investments.* —ED.

Pro & Con: Soft Packings

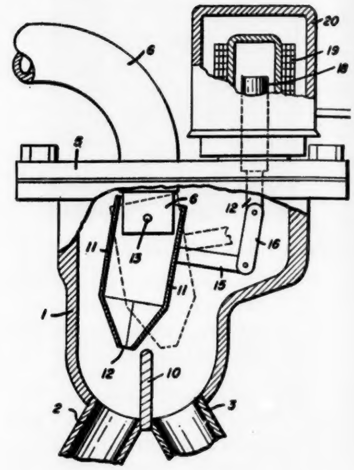
Sir:

Mr. Tracy's article, "Select Best Pump Seal," in your April issue (pp. 239-254) is one of the best and most comprehensive articles that has been published on the subject of mechanical seals.

The only part of the article with which I disagree is that covering the use of soft packing (Figs. 13-16). All these designs, particularly the arrangement shown in Fig. 15, would result in a very short operating life and would require constant supervision.

It seems to be assumed for the other arrangements that leakage must be accepted, since provision is made for water quenching. There are numerous cases in chemical operations

PEOPLE . . .
LETTERS:



Con: Patent Infringement

Sir:

I have read your Plant Notebook item, "New Reflux Splitter Resists Corrosion," by L. T. Haire and S. R. Eckhaus, as it appears in your December 1956 issue (p. 220).

The device as described in this article is covered by our patent (U. S. 2,518,574), with other claims pending. The authors of the article have conflicted with our interests in building such an apparatus without our permission and in instructing others to do likewise.

Automatic reflux splitters of the type described are manufactured by us and distributed on a nationwide basis.

P. N. HEERE
Distillation Engineering Co.
Livingston, N. J.

Not Yet, Anyway

Sir:

You have done an excellent job with the April cover and the article on "How to Check Equipment Quality" (pp. 261-266).

However, there is an error in the biography of the author (pp. 331-332). Mr. Veith's title is chief inspector, not chief engineer.

F. C. BREUNINGER
E. I. du Pont de Nemours & Co.
Wilmington, Del.

PRO & CON

C. H. CHILTON

Better Estimating Methods

Sir:

Your editorial on the need for more cost data (April 1957, p. 3) was interesting, and I wish you luck on obtaining additional data.

You say that no more is needed on "estimating methods." I think you must refer chiefly to methods of fixed capital cost estimation, and I agree that enough has been written on this subject. This is also the chief area where very little recent data have been published on a correlated basis.

However, methods of estimating working capital and direct manufacturing costs (particularly their overheads) are, I think, neglected in the literature, and much more needs to be published on them. Also, I feel that more needs to be published on methods for profitability determination after all the forecasts have been made.

JAMES B. WEAVER
Atlas Powder Co.
Wilmington, Del.

▶ *Look for articles now in preparation which will deal with belt conveyor costs, piping costs and evaluation of capital investments.* —ED.

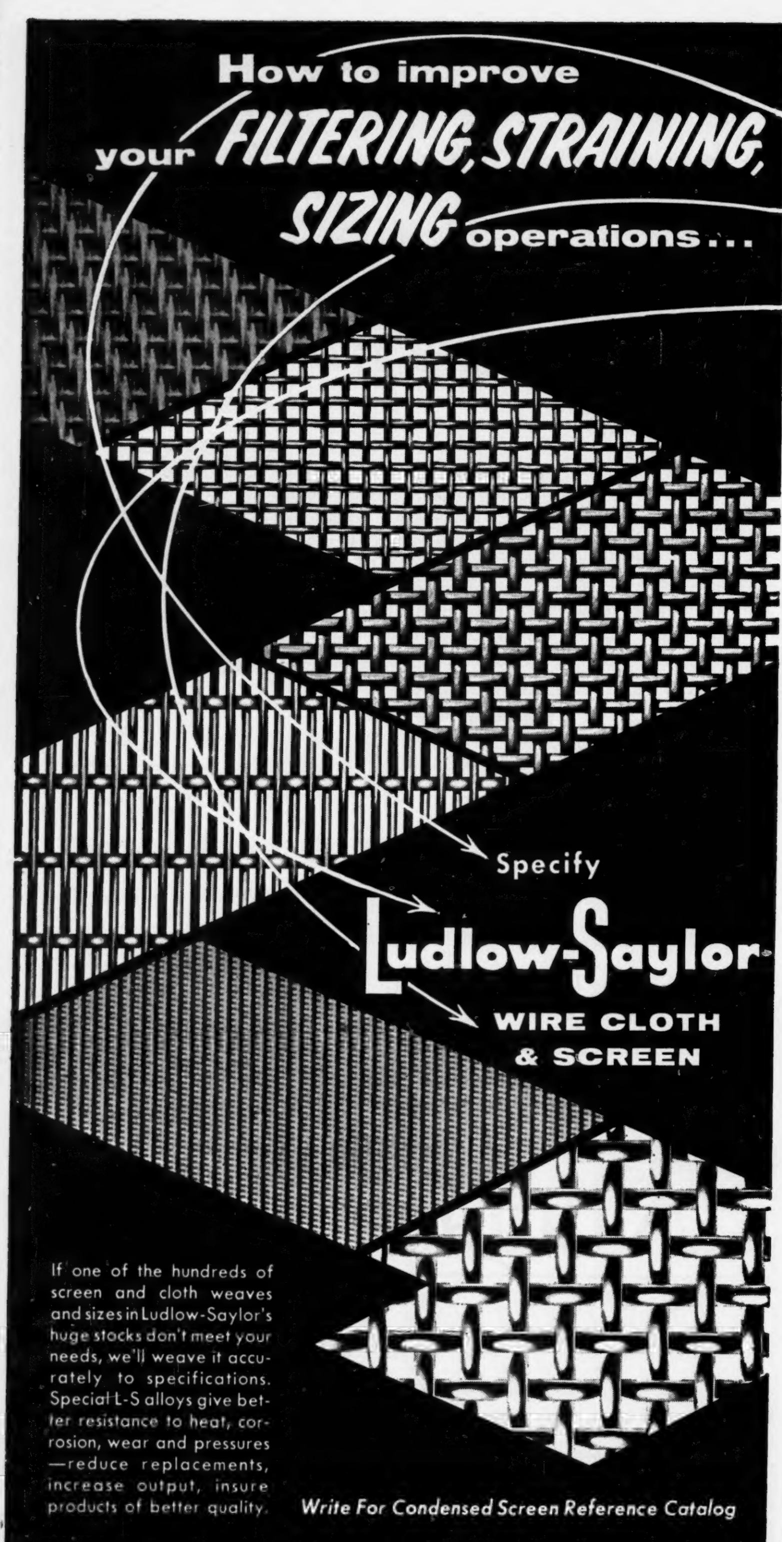
Pro & Con: Soft Packings

Sir:

Mr. Tracy's article, "Select Best Pump Seal," in your April issue (pp. 239-254) is one of the best and most comprehensive articles that has been published on the subject of mechanical seals.

The only part of the article with which I disagree is that covering the use of soft packing (Figs. 13-16). All these designs, particularly the arrangement shown in Fig. 15, would result in a very short operating life and would require constant supervision.

It seems to be assumed for the other arrangements that leakage must be accepted, since provision is made for water quenching. There are numerous cases in chemical operations



where this would be a nuisance and would be undesirable.

Although this may seem to imply that soft packings are generally unsatisfactory, this is not my intention. Soft packing arrangements have been designed and are giving excellent performance in many services for pressures of more than 5,000 psi. Especially in existing installations, it is usually more convenient and much less expensive to adapt a well-designed soft packing arrangement than to try to apply a mechanical seal.

While Mr. Tracy has limited his comments to centrifugal pumps, good applications of soft packing and mechanical seals are often required for other equipment with rotating shafts, such as autoclaves, compressors and mixers.

WALTER COOPEY
Engineering Consultant
Charleston, W. Va.

Provincial Error

Sir:

I have no doubt that Edmonton, Alberta, would like to move to British Columbia, but this just could not happen. Their capital investment is too high. The fact that they can't move their acreage is secondary.

D. G. DIX
Technical Assistance Adm.
United Nations, N. Y.

► *We misplaced the city of Edmonton in a news item on p. 351 of our March issue.*—ED.

Pro: Correct Equation

Sir:

In your December Refresher, shouldn't Eq. (2) read

$$dP/P = (\Delta H/R)(dT/T^2)$$

BRUNO OGSTO
Fenn College
Cleveland, Ohio

► *Thanks to a sharp-eyed student for catching this error and bringing it to our attention.*—ED.

Wrong Hometown

Sir:

In your Process Flowsheet on tetracycline (Mar. 1957, pp. 228-231), Bristol Laboratories is listed as being in Schenectady, instead of Syracuse. We would

appreciate it if you would please correct your records.

P. I. Bowman
Bristol Laboratories
Syracuse, N. Y.

Pro & Con: Gas Conductivity

Sir:

I have read with extreme interest the article by Wallace R. Gambill, "You Can Predict Gas Conductivity" (Apr. 1957, pp. 277-282).

The author has done an excellent job of bringing together the diversified literature. He has succinctly pointed out the different techniques that have been developed for the prediction of gas conductivities for pure compounds as well as mixtures, including effects from ideality based on differences in molecular size.

He has also done a very good job in considering the deviations of ideality due to highly polar compounds, where differences in molecular kind occur, and in the treatment of such mixtures.

I want to compliment you on the excellent job that *Chemical Engineering* is doing.

B. W. Gamson
Borg-Warner Corp.
Des Plaines, Ill.

Sir:

Mr. Gambill's article in April is a fine contribution and will be of great value in solving the difficult problem of predicting good thermal conductivity values.

However, in one instance Mr. Gambill appears to have selected an erroneous equation, attributed to Franck (Ref. 21 in the article), which gives the thermal conductivity correction for a reacting gas mixture:

$$k\alpha = \frac{DP\,(\Delta H)^2\,\alpha\,(1-\alpha)}{R^2T^3\,(1+\alpha)} \qquad (8)$$

J. O. Hirschfelder ("Heat Transfer in Chemically Reacting Gas Mixtures," WIS-ONR-18, University of Wisconsin, 1956) has derived the correct expression:

$$k\alpha = \frac{DP\,(\Delta H)^2\,\alpha\,(1-\alpha)}{2R^2T^3}$$

Actually, the equation attributed to Franck was originally derived by Nernst in 1904. Nernst made the mistake of as-

suming the simple diffusion equation to hold, which is valid only for equal molal counter-diffusion not encountered in the chemical reaction system

$$X_2 \rightleftharpoons 2X$$

for which the thermal conductivity equation was developed.

In support of Hirschfelder's theoretically exact equation, I can report agreement with my own data presented in a paper, "Heat Transfer to a Gas-Phase Chemical Reaction," at the recent ACS meeting in Miami.

W. SCHOTTE
E. I. du Pont de Nemours & Co.
Wilmington, Del.

Pro: Deflating the Boom

Sir:

In your Annual Review, "Population Boom Challenges Chemical Technology" (Jan. 1957, pp. 211-226), it seems that you left out all the advances, both in chemistry and chemical engineering, in the area of population control.

Pharmaceutical companies provided several experimental materials of the nortestosterone type to clinicians who demonstrated the physiological control of fertility through the oral route with them. In addition, reserpine was found to have an interesting antifertility effect in monkeys; this is being explored further.

The population variable, in a decade or so, may no longer be independent—even of chemical engineering!

It is a pity that this report

did not rise to the challenge of fitting progress in chemical technology into some kind of unified world view so that some items would assume greater importance than the others and thus might be given proper emphasis. Its title made me hope for a moment that this is what you really intended to do, but as I proceeded I realized that there was actually too little time for the necessary sifting and appraising process. What I was hoping for is a research task of considerable magnitude which could not be carried out in the few weeks available to you.

One of the things that would certainly come out of a systematic approach is the realization that increasing standards of performance set by the consumer are reflected in narrower and narrower specifications and in the substitution of known chemical formulations for natural products. In every instance that an intuitive assertion was made in your Review that a certain development promised to be important, it was because it appeared to make a strong contribution to the meeting of narrow specifications in some known operation.

Perhaps the operations researchers will be able to quantify this kind of progress some day.

R. L. MEIER
Ann Arbor, Mich.

▶ *Those interested in fitting chemical engineering developments into a "unified world view" will do well to read Dr. Meier's recent book, which we reviewed in January (pp. 289-290).*—ED.

Pro: Evaporator Control

Sir:

This letter is in reference to the article by George Weber on evaporator control in your February issue (pp. 248-9).

We agree with the author's statement that the boiling-point-rise method is not new. We have used exactly the same control scheme in commercial evaporators for at least the past ten years. The only difference is that we have usually found it unnecessary to purge the reference resistance bulb with steam.

F. C. STANDIFORD
Consulting Chemical Engineer
Ann Arbor, Mich.

PEOPLE . . .

NAMES IN

C. Andy Harwick:

Man of the Month

Chemico hauls retired Ebasco executive out of retirement to fill key post as vice president

Some people don't know when to retire: others don't get the chance even if they want it.

When Chemical Construction Corp.'s C. Andy Harwick retired from Ebasco Services, Inc.,* last year, he thought he'd do some of the things he'd always said he'd do if only he had the time. Those "famous last words" were hardly out when Chemico,* under new management, hastily summond him back to the grindstone. But, some people rather enjoy a good grindstone and this must be true of Harwick or Electric Bond & Share never could have dragged him out of retirement so easily.

► **Back in the Saddle**—So, when we saw him the other day, he was huddled behind a desk again, scrutinizing some new

* Both firms are subsidiaries of Electric Bond & Share Co.

contracts. Before him was a pile of paperwork to be polished off (there was another, larger, stack in back of him, by the window). Besides the contracts —mostly for heavy chemicals plants—there was also some advertising copy to be checked as well as an itinerary. (Harwick was about to fly to London to talk things over with Chemico's British affiliate).

For, in this vice presidential post, Harwick has—what adds up to—the last word on all of Chemico's major operations. That is, it's his job to oversee such activities as research, development, engineering, cost estimating, construction and purchasing.

And, despite (or because of) the heap of work involved, Harwick is having the time of his life with his new challenge.

►**The Man for the Job**—Harwick took on his present assignment some months back, just after Chemico's ownership was transferred from American Cyanamid to Electric Bond & Share. Before that—for twelve years or so—he had headed up Ebasco's industrial engineering department where duties included the planning, design, and construction of various industrial plants. The bulk of his early career was spent with H. K. Ferguson Co., Cleveland. He started out with Ferguson in 1925 and held down a vice president's post by the time he joined Ebasco, twenty years later.

With this impressive work record in back of him, it's little wonder that he was singled out for the Chemico assignment.

There were other reasons, though.

For one thing, he was known to have a talent for sorting out the guts of any problem and for coming up with a solution simultaneously.

But more than that, Harwick had a top-flight reputation for handling people. Staffers at Ebasco say that he could establish close rapport with anybody—without much effort.

No doubt about that.

When you meet Harwick, you feel at ease even before you've had time to shake hands. He's relaxed and casual and makes you feel as though he had nothing else to do at that particular moment than talk to you.

▶ **Boosts Morale**—This easy rapport means something to his staff, too. Ebasco's Jack Lynch (who had worked with Harwick since 1935) reports that "Andy" became a sort of father-confessor for his assistants and coworkers. He used to listen to everybody's troubles and, once in a while, staffers found themselves waiting in line for their turn.

Harwick was known, too, for his practiced knack in pointing out mistakes—the right way. Lynch recalled that at a restaurant one day, he, Harwick and some friends had their tea leaves "read." When the scattered designs in his cup were deciphered, Harwick was "diagnosed as a very diplomatic boss without any tact." Ebasco people agree: When Harwick had to correct anyone, what he was driving at was always perfectly plain but it could never be taken as a personal reprimand.

And, at Chemico, Harwick already has a reputation for knowing how to keep staff morale up on a level where it functions best.

John Handy, the firm's financial vice president, told us that "when you work closely with Andy Harwick, you easily can appreciate his way of bringing out the best in everyone around him. Through his humility and basic understanding of the people and problems of this industry, he has instilled confidence in the entire Chemico organization."

And Chemico's manager of construction, B. I. Walker, sums up his reactions to Harwick this way: "It was just a case of how an employee found his boss."

Unaffected, always himself, Harwick is liked for his way of putting his cards on the table without any trace of high-rank smugness.

▶ **Travel Bug**—When Andy Harwick left Ebasco, he received a

set of traveling bags as a farewell gift. Apparently, it was pretty obvious—at least to his associates—that he and Mrs. Harwick would soon head for points unknown. Where exactly, no one could guess: His many business trips and his own excursions seem to have left few places unseen. Very likely, though, there wouldn't have been any specific destination. On past trips, the Harwicks had a habit of taking off and improvising along the way. They stopped whenever anything caught their interest.

All told, Harwick has spent about ten months in India and has even taken the globe-circling route once. Though he's enthusiastic about all of Europe, Harwick's raves are reserved exclusively for Athens and Rome.

His major hobby, color photography, ties in well with all of this. But his other pastime, gardening, is a curious contrast to his wanderlust tendencies.

▶ **Before and After**—Harwick was born in the Finger Lake district of New York State. He earned his bachelor's degree in chemistry at the nearby University of Rochester in 1913.

Today, the Harwicks live in Summit, N. J. On top of his direct duties with Chemico, Harwick is also president of the firm's Canadian subsidiary and a director of its British affiliate. He holds professional licenses in eleven states and membership in the American Institute of Chemical Engineers.

Donald M. Nelson, chairman of the board of Electronized Chemicals Corp., Beverly Hills, Calif., has received a Missouri Honor Award for distinguished service in engineering from the University of Missouri.

J. L. Galt has been named West Coast marketing manager for GE's chemical materials department, in Anaheim, Calif.

Robert C. Kintner, professor of chemical engineering at Illinois Institute of Technology,

Chicago, has been selected to give the Distinguished Faculty Lecture of the Year for the Illinois Tech chapter of Sigma Chi.

Ralph Ericsson has been named general sales manager of Texas Butadiene & Chemical Corp.

A. J. Broggini

Badger Manufacturing Co., Cambridge, Mass., has named A. J. Broggini, 44, as president.

In addition to his new duties, Broggini will continue as chairman of the executive committee. He's a member of the company's board of directors as well as a director of Belgian and Dutch subsidiaries.

Broggini graduated from the University of Michigan in 1934 with a degree in chemical engineering. He lives in Wellesley Hills, Mass.

Harrison C. Paulus is now supervisor of market research, new products division, Minnesota Mining & Mfg. Co., St. Paul, Minn.

R. Bruce Arnold and **H. William Sterritt,** both students at the University of Maine, have been named recipients of the J. L. Ober Award of the Scott Paper Co. Sterritt and Arnold are studying chemical and mechanical engineering, respectively.

John J. Miller has been appointed general manager of the alumina division of Olin Revere Metals Corp., in Burnside, La. He had been with Aluminum Co. of Canada, Ltd.

William T. Ahlborg has been selected executive vice president and general manager of Denver Equipment Co. **F. J. Griesemer** has been advanced to assistant general manager.

Herschel G. Harris has been elected president of New York Rubber Corp. to succeed **Mark H. Stratton**—retiring president. **C. Bradley Allen** has been elected executive vice president and a director.

William J. Lawless has been promoted to division superintendent of the Smiths Bluff refinery of Pure Oil Co., Nederland, Tex. He has been assistant superintendent since 1953 and acting superintendent since last year.

Martin D. Robbins

Latest addition to the *Chemical Engineering* masthead is Martin D. Robbins.

Robbins is a graduate of Tufts University where he received a B. S. in chemistry in 1954. Last year, he earned an M. S. in ceramics at MIT.

At the Cambridge school, where he was a research assistant, he worked on a variety of problems dealing with glass and high temperature materials. Robbins left MIT to join du Pont's electrochemicals department as a process engineer.

As you might expect, Robbins' training in ceramics has resulted in a consuming spare time interest in ceramic art. In fact, there have been times in the past when his friends have been bombarded with his various works of art—Marty never has room for them at home.

A healthy contrast to his

artistic interests, is Marty's flare for sports cars. He's the proud owner of an MG.

Though he's managed to stay away for quite a bit of the last few years, Marty is a native of Brooklyn. He's also an active member of the ACS and the American Ceramic Society.

Richard McGhee

Commercial Solvents Corp. has named Richard M. McGhee as chief engineer, with headquarters in Terre Haute, Ind.

McGhee has been associated with CSC engineering activities for the past 14 years. Responsibilities have included an assignment as project engineer for the firm's nitroparaffins production facilities at the Sterlington, La., plant. Before that time he was head of derivative operations at CSC's Terre Haute, Ind., plant.

A graduate of Purdue University in chemical engineering, McGhee also holds a master's from the University of Michigan.

G. A. Walley has been named chief engineer in charge of the Panellit, Inc., manufacturing facilities in Alhambra, Calif. He had been the firm's senior project engineer.

Walter H. Duve, production superintendent for Napko Corp., paint manufacturers, is now vice president in charge of production. Chemical Engineer **Sidney V. Smith** is now vice president in charge of sales, retail stores and merchandising.

H. Rush Spedden has been appointed director of research

of Union Carbide Ore Co. He will be responsible for operations at UCC's nuclear research center in Sterling Forest, N. Y. Spedden has been in charge of the minerals research department of the firm's research labs in Niagara Falls, N. Y., since 1952.

A. N. Wohlwend, director of commercial development of Escambia Chemical Corp., has been appointed vice president of the firm.

Thomas R. Steadman has been appointed manager of Grace Research & Development's miscellaneous organic chemicals group, in New York. For the past five years, Steadman has been associated with National Research in Cambridge, Mass.

J. C. Denis is now director of research and development for Penberthy Mfg. Co., Detroit. Denis joined the firm in 1925. He is one of the pioneer designers of the modern sump pump.

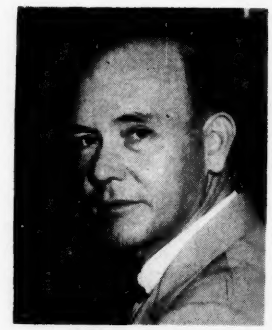
Julian A. Rogers

W. R. Grace & Co.'s polymer chemicals divisions has appointed Julian A. Rogers head of the manufacturing department at its high density polyethylene plant in Baton Rouge, La.

Formerly, Rogers was head of the ammonia department of Grace Chemical Co. in Memphis, Tenn. Before joining Grace, Rogers was ammonia plant superintendent for Mississippi Chemical Corp. and chief supervisor of Hercules Pow-

der's ammonia plant in Hercules, Calif.

Rogers attended Peabody College and Southern Methodist University. He is a member of the AIChE and the Armed Forces Chemical Assn.



Walter F. Rogers

Chief chemist of Gulf Oil's Houston production division chemical unit—Walter F. Rogers—has received the Willis Rodney Whitney Award of the National Association of Corrosion Engineers.

Rogers, a founding father of the organization, is the tenth man to receive the award, given annually for contributions to the world's knowledge of corrosion control.

Born in Tyler, Tex., Rogers joined Gulf Oil in his native state, at the Port Arthur refinery, as a chemical engineer. He studied chemical engineering at the University of Pittsburgh where he earned a B. S. as well as a professional degree.

Harold J. Rose has been appointed assistant general manager of Esso Standard Oil's chemical products department, New York.

Ethyl Corp., New York has announced these promotions: **W. Burke Grandjean** to superintendent of business information, **Merle Gould** to assistant director in process development, **J. B. Bingman** to acting supervisor in process design.

E. W. Carey has been elected vice president of Fibreboard Paper Products Corp., San

Francisco. He had been with U. S. Gypsum.

Melvin A. Hanson has been appointed chief engineer of the Magnus Metal division of National Lead Co., in Chicago.

Gilbert Brown and **Janet Lee Watkins,** former nuclear engineers with Combustion Engineering and GE respectively, have joined General Nuclear Engineering Corp., Dunedin, Fla.

Miller W. Swaney

Recently appointed coordinator of chemicals and lube oil processes for Esso Research & Engineering Co. is Miller W. Swaney.

Formerly, Swaney had been director of the products research division. His first assignment with Esso was in 1939 as a research chemist. During the War, he was a member of the U. S. Government's rubber reserve polymer research committee.

The new research chemicals chief was born in Gallatin, Tenn. He earned his degree in chemical engineering at Nashville's Vanderbilt University.

T. J. O'Connell of the Macklin Co., Jackson, Mich., has been elected national chairman of the newly formed American Society for Abrasives, Reading, Pa.

John A. King has been appointed director of research for Armour & Co., Chicago, Ill.

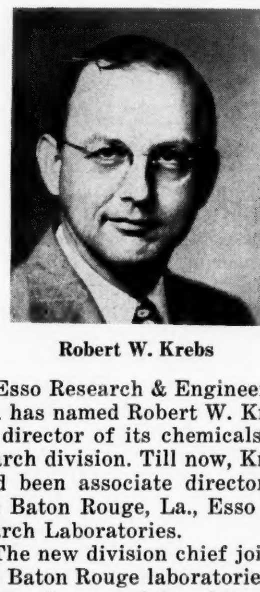
Harry E. Knox, Jr. has been appointed general works man-

ager in charge of Acheson Dispersed Pigments Co.'s plants in Philadelphia, Orange, Tex., and Xenia, Ohio.

John E. Yocom has been appointed director of technical services for the Bay Area Air Pollution Control District, with headquarters in San Francisco.

Erich Schleser has been made chief plant engineer and **R. T. Romans** chief process engineer of Amoco Chemical Corp., in Texas City, Tex.

Emil Mazzarella has been promoted to supervisor in general application, paper technical group, National Starch Products, Inc.



Robert W. Krebs

Esso Research & Engineering Co. has named Robert W. Krebs as director of its chemicals research division. Till now, Krebs had been associate director of the Baton Rouge, La., Esso Research Laboratories.

The new division chief joined the Baton Rouge laboratories in 1937 after receiving his doctorate in chemical engineering from the University of Illinois. He advanced to assistant director of the laboratories in 1947 and to associate director in 1954.

Krebs made major contributions to the development of fluid catalytic cracking, butyl synthetic rubber, hydrocarbon synthesis and the fluid coking process.

He is a past president of the Louisiana Ornithological Society.

William P. Orr

Celanese Corp. of America has appointed William P. Orr assistant general manager of the plastics division.

Formerly, Orr served as plant manager of the new Celanese polyolefin plastic plant in Houston, Tex. He originally joined the firm in 1945 as a chemical engineer in process operations at the Bishop, Tex., chemical plant. In 1952, he became assistant to the manager of the chemical division's plant operations and, two years ago, he was appointed project manager of that division.

In late 1955, Orr was transferred to the firm's plastics division to serve as project manager for the design, engineering and construction of the Houston plant. Last year, he became plant manager.

A. J. Williamson has been named president of Tube Reducing Corp., Wallington, N. J.

John F. Babbitt has just been appointed a sales engineer in Chemical Construction Co.'s New York office.

Arthur C. Ellsworth, Jr., has been appointed special projects engineer for Columbia-Southern Chemical Corp. Formerly, Ellsworth was assistant director of development for the firm's chemical producing plant at Natrium, W. Va.

J. C. Wright, resins group leader in process development at Carbide & Carbon Chemicals Co., has been promoted to the post of as-

sistant to the product general manager for vinyl resins in New York.

James E. Iliff

Davidson-Kennedy Associates Co. has appointed James E. Iliff as vice president-general manager. In his new assignment, Iliff will direct the Chicago office of the engineer-contractor firm.

Formerly, Iliff was chief process engineer of the Blaw-Knox Co., chemical plants division, midwest headquarters. While at Blaw-Knox, he organized the chemical process engineering department and pioneered that company's entrance into the design and construction of fertilizer plants.

Iliff studied chemical engineering at Iowa State College.

Francis O. Rice, head of the department of chemistry at Catholic University of America, received the 1957 Hillebrand Award of the ACS for a "notable contribution to chemistry."

William L. Root, 3rd, has joined Bethlehem Foundry & Machine Co. as chemical process equipment sales representative.

Graham C. Mees has been appointed president of Distillation Products Industries, division of Eastman Kodak Co., Rochester.

Desmond M. C. Reilly has been named manager of technical information for Food Machinery & Chemical Corp.'s organic chemicals division.

Guy C. Quick, Jr., has been named field superintendent for the construction of Chemstrand Ltd.'s new Acrilan acrylic fiber plant in Coleraine, No. Ireland.

E. Justin Wilson, Jr., has been appointed research director for Detroit Controls Corp., Redwood City, Calif.

OBITUARIES

Carlton W. Crumb

Dorr-Oliver's director of technical data—Carlton W. Crumb—passed away after a brief illness, on April 6, in Stamford, Conn.

Crumb had been with the Connecticut firm for nearly thirty years. In fact, he joined Dorr-Oliver immediately after earning his degree in chemical engineering at the University of Michigan, in 1928. Over the years, he served in various sales promotion and development positions until he took on his latest post in October 1955.

Our editors and readers remember Crumb, in particular, for the fine help he gave us in preparing the 64-page report on solids-liquids separation (Chemical Engineering, June 1955). Crumb served as adviser for the 26-page section on filtration and furnished us with a large number of illustrations.

Crumb was a native of Bainbridge, N. Y.

Gunter H. Gloss, supervisor of inorganic chemical research for International Minerals & Chemical Corp. died suddenly, February 24, at his home in Mundelein, Ill., after a heart attack.

PEOPLE . . .

FIRMS IN

NEW LINES

Carbide & Carbon Chemicals Co., will enter fluorocarbons field with a 50-million lb./yr. unit at its Institute, W. Va., plant. On-stream date is slated for late 1958.

Delhi-Taylor Oil Corp. will begin marketing benzene, toluene and xylene about mid-year. New venture, along with minerals exploration, will call for $15-million expenditure.

Dravo Corp., Pittsburgh, Pa., has been licensed by Carl Schenck Co., Darmstadt, Germany, to make Schenck designed vibrating feeders, screens and conveyors in U. S.

Davison Chemical Co., is making available to refiners an alkylated phenol as an anti-oxidant for gasolines and other petroleum derivatives. Tradenamed "Dav-ad 101", chemical is 2, 6-ditertiary-butly-4 methylphenol.

Schwarz Laboratories, Inc., Mount Vernon, N. Y., has announced that many of its radiochemicals are available in solution form, with specific activities 10 to 100 times higher than the standard crystalline preparations.

Olin Mathieson's industrial chemicals div. is offering two new lube-oil additives, Omavis 10 and 20, for viscosity-index improvement.

Abbott Laboratories, North Chicago, Ill., within the next few months will market a new ethical-drug tranquilizer, Harmonyl, an alkaloid of *rauwolfia canescens.*

Pfister Chemical Works, Ridgefield, N. J., will soon be marketing new lines of organic intermediates, including primary amines, nitro compounds, chlorinated compounds, carboxylic acids and

acid chlorides, sulfonic acids, hydroxy and alkoxy compounds.

NEW NAMES

Universal Atomics Corp., Westbury, Long Island, N. Y., has changed its name to Universal Transistor Products Corp. Electronic and nucleonic instruments division becomes Universal Atomics Div. of UTP.

Bros Inc., is the new name of Wm. Bros Boiler & Mfg. Co., Minneapolis, Minn., maker of industrial steel-plate fabrications.

American Cyanamid has announced a change in name of its mineral dressing department to Mining Chemicals Dept.

A. J. Griner Co., Kansas City, Mo., lab-equipment supplier, has adopted the name of its parent company, Chicago Apparatus Co.

Raymond Laboratories, Inc., subsidiary of Rayette, Inc., has changed its name to Rayette Inc., Chemical Div.

Columbia-National Corp. is the new name of NRC Metals Corp.

NEW FACILITIES

W. R. Grace & Co. is building a plant at Irwin, Tenn., to produce uranium, thorium and rare-earth alloys and metals for nuclear reactors. Installation will include solvent-extraction unit, reduction unit and a metal and casting plant.

Surface Combustion Corp., Toledo, Ohio, is building 24 furnace units for Erie Mining Co.'s \$300-million taconite project at Hoyt Lakes, Minn.

FIRMS . . .

Surface has acquired exclusive rights to license Erie's iron-ore pelletizing process and equipment.

Shell Oil Co. has scheduled mid-1958 as on-stream date for its Fluor-Corp.-built, 2,400-bbl./day sulfuric acid alkylation unit at its Anacortes, Wash., refinery. Construction begins this October.

American Cyanamid's industrial chemicals division this year will install a calcining unit at Bauxite, Ariz., to treat ore for making aluminum sulfate at its nine domestic plants.

Dow Chemical Co. has bought a 50% interest in Sales y Alcalis, S. A., a Mexican Corporation which owns extensive salt-mining rights on the Isthmus of Tehuantepec. Dow acquired rights to manufacture caustic soda, chlorine and related products.

Cabot Carbon Co., subsidiary of Godfrey L. Cabot, Inc., will build a silicon oxide pigment plant at Tuscola, Ill. Process used will be vapor-phase hydrolysis of silicon tetrachloride.

Esso Research & Engineering has announced plans for a large technical computing center at Linden, N. J. Center will include an IBM 704 computer, one of two (Indiana Standard has one at Whiting) in the whole oil industry.

Societe Ugilor has begun making hydrocyanic acid, acetone cyanohydrin and acrylonitrile in its new plant at Saint-Avold in the Moselle, will be making acrylic and methacrylic esters by early 1958.

Shell Oil Co. of Canada will build Canada's first epoxy resin plant near the company's Montreal East chemical plant. Cost of project will be $1 million.

Commercial Solvents Corp. stockholders have approved the merger of CSC with Thermatomic Carbon Co.

Olin Mathieson Chemical Corp.'s new more-than-$750,000 sodium silicofluoride plant at Pasadena, Tex., is now in full operation.

Reichhold Chemicals, Inc., has begun producing formaldehyde at its new Tacoma, Wash., plant. Present capacity is 20 million lbs./yr. (See p. 146 for some details of Reichhold formaldehyde process.)

Shell Chemical Corp. has just completed a new unit at its Denver, Colo., plant to produce methyl parathion, an organic phosphate insecticide.

Stauffer Chemical Co. has completed a major office expansion at Omaha, Neb., to accommodate larger sales and manufacturing staffs.

Parke, Davis & Co. will erect a one-story building at Menlo Park, Cal., to house company operations for northern Cal., western Nev. and Hawaii.

Standard Oil Co. (Ohio) has started construction on new $40-million refinery facilities at Toledo, Ohio. New facilities will boost refinery capacity from 30,000 to 60,000 bbl./day.

British American Oil Co. has announced plans for a multi-million-dollar, 20,000-bbl./day refinery at Port Moody, B. C. Refinery is scheduled for completion in 1958.

Air Reduction Sales Co. will build an air liquefaction plant at Acton, Mass., costing over $9 million. Plant will be completed in summer, 1958.

Central Farmers Fertilizer Co., Chicago, will build units at Georgetown, Idaho, to process phosphate rock and calcium metaphosphate. Rock unit is slated to be on stream in late 1957; metaphosphate unit, in 1958.

Merichem Co., subsidiary of Jefferson Lake Sulphur Co., is doubling capacity of its cresylic acid plant, boosting

FIRMS . . .

it to about 2.5 million gals./yr.

Phillips Pacific Chemical Co. has started production at its 200-ton/day Coulee ammonia plant in southeastern Wash.

Chemstrand Corp. is scheduling a 50% expansion of capacity at its acrylic fiber plant at Decatur, Ill., boosting output from 30 million to 45 million lbs./yr.

Foremost Food & Chemical Co.'s El Dorado Div., Oakland, Cal., has more than doubled its coconut-oil fatty acid and methyl ester capacity.

Gulf Oil Corp. has acquired a minority interest (surmised, by some observers, to be 25%) in Callery Chemical Co., through a stock purchase.

Texas Portland Cement Co. has started operations at its new cement plant at Orange, Tex. Engineered by Kennedy-Van Saun, plant has an initial capacity of over 700,000 bbls./yr. of high-grade Portland cement.

Iraq Development Board has scheduled Basrah fertilizer plant's on-stream date for 1960. The 250,000-ton/yr. plant will cost about 8.5 million Iraqi dinar ($23.8 million). Swiss firm, Ammonia Casale, will act as engineering consultant.

Du Pont Co. late this year will complete a new production unit at its East Chicago, Ind., plant to manufacture sulfamic acid and Ammate weed killer. New unit will double output of both products.

Gonzalez Chemical Industries, new Puerto Rican firm with heavy U. S. private financing, has started up its 40,000-ton/yr., $12½-million anhydrous ammonia plant in Guanica, on Puerto Rico's south coast. Unit will use Texaco synthesis-gas process.

Monsanto Chemical Co. has completed a 60% expansion in phthalic anhydride capac-

ity at its Everett, Mass., plant.

Electric Steel Foundry Co. has purchased a 22-million-volt Betatron for metallurgical laboratory work at its Portland, Ore., plant to complement its 220,000-volt X-ray and cobalt-60 radiographic facilities.

Fisons Ltd., has started work on a new $5.6-million fertilizer plant at Bamford, near Ipswich in Suffolk, England. Plant will turn out more than 60,000 tons/yr. of fertilizer.

Atlantic Research Corp., Alexandria, Va., has acquired U. S. Flare Corp. & Associates. Both companies have been active in the rocket and missile field.

San Francisco Chemical Co., Montpelier, Idaho, is beginning work on 360 acres of phosphate leases in the Swan Lake, Idaho, district. High-grade phosphate will be strip mined and sent to market. Low-grade rock will either be marketed or sent to Leefe, Wyo., for beneficiation.

R. J. Strasenburgh Co., pharmaceutical manufacturer plans to build a $1-million building near Rochester, N. Y. to house research and manufacturing facilities.

Polymer Chemicals Div., W. R. Grace & Co., has officially opened its main offices and laboratories in Clifton, N. J.

Carrier Corp. has concluded an agreement with Elliott Co. whereby the latter will be merged into Carrier. Elliott manufactures steam turbines, heat transfer apparatus, electrical and industrial process equipment.

Physical Institute of Munich University will acquire a nuclear research pile, larger cobalt-radiation apparatus and an electron gun.

Mobil Overseas Oil Co. will be one of a group of companies to build a 65,000-bbl./day re-

finery in Turkey. Other companies: Caltex, Shell, British Petroleum. Total cost will be $48 million, when refinery goes on stream in 1960.

Sifrance, Paris, France, will build a plant at Nogent L'Artaud (Aisne) on the Marne River, to manufacture sodium meta- sesqui- and orthosilicates via Cowles Chemical Co. process.

Carbide & Carbon Chemicals Co. has doubled ethanolamines capacity at its Seadrift, Tex., plant.

Olin Mathieson Chemical Corp. has spent $8 million to boost chlorine-caustic output at McIntosh, Ala., to 250 tons/day of chlorine and 280 tons/day of caustic soda.

Naugatuck Chemical Div. of U. S. Rubber Co. has upped production of Paracril synthetic rubber by 60% at its Baton Rouge, La., plant.

Cal-Mex Oil & Refining Co., subdivision of Vereinigte Petroleum Werke of West Germany has let to Ralph M. Parsons Co. a $27-million engineering contract for a 20,000-bbl./day refinery, probably in South Bay area of San Diego. Tentative completion date: early 1959.

Archer-Daniels-Midland Co. has purchased soy-protein business and facilities at Evendale, Ohio, from the Drackett Co., Cincinnati.

Escambia Chemical Corp. is building a 50,000-sq. ft. research and development center at Wilton, Conn. Center is scheduled for occupancy early in 1958.

Volunteer Portland Cement Co. has begun a $435,000 expansion program at its Knoxville, Tenn., plant, which will increase capacity by 30-40%.

Rhodesia Wattle Co. has started tannin production in the first of its extraction plants near Melsetter in the Federation of Rhodesia and Nyasaland.

When the two other rising plants go on stream, output will be 8,000 tons/yr., valued (at current prices) at $2.5 million.

Vickers Petroleum Co. is building a $2-million petrochemical plant at its Potwin, Kan., refinery. On-stream date: January 1958.

Champion Paper & Fibre Co. will build a $2.5-million chemical recovery smelter and precipitator at its Pasadena, Tex., plant.

Dow Chemical Co.'s Texas div. will boost its synthetic glycerine capacity to double present output by March 1958, by adding a unit which will use the Dow-developed process involving propylene and chlorine as starting materials.

Linde Air Products is building an acetylene plant at Montague, Mich.

NEW LOCATIONS

Hagan Chemicals & Controls, Inc., will move its headquarters offices and research center from downtown Pittsburgh, Pa., to a 27-acre site on Penn-Lincoln Pkwy. West, 10 miles from the downtown area.

Emulsol Chemical Corp., manufacturer of surface-active agents, has moved sales and administrative offices to 75 E. Wacker Dr., Chicago, Ill.

NEW COMPANIES

Chemstrand Corp. has reached agreement with Societa Edison of Milan, Italy, to manufacture acrylic fibers in that country by a newly formed subsidiary of Societa Edison. Chemstrand will be minority stockholder.

Air Products, Inc., has formed a subsidiary, British Air Products, to make low-temperature equipment and industrial gases in the United Kingdom, British Common-

wealth and Europe. Subsidiary is now building a large-tonnage oxygen plant at Corby in Lincolnshire.

Ink Masters, Inc., Chicago, Ill., has been formed to manufacture printing and lithographic inks.

Firth Sterling (Canada), financed jointly by Firth Sterling, Inc., and Canadian interests, has been formed to produce sintered tungsten carbide tips for rock bits. New company is now building a plant at Brantford, Ont.

Glenn Chemical Co., newly organized firm in Chicago, Ill., will make Tabutrex, a new insect repellent.

Emery Industries, Inc., Cleveland, Ohio, has formed Emery Industries (Canada), a wholly owned subsidiary, to make fatty acids for Canadian market. New firm has acquired fatty-acid facilities of S. F. Lawrason & Co., London, Ont.

C. W. Reed Co., Los Angeles, has been formed to offer sales and service representation on the West Coast for technical equipment manufacturers. Firm will handle wide line of nuclear products.

NEW REPRESENTATIVES

N. S. Wilson & Sons, Boston, Mass., has been named by Arizona Chemical Co., as distributor of Acintol tall-oil chemicals in Me., N. H., Mass., Vt. and R. I.

C. G. Sargent's Sons Corp., Granitesville, Mass., maker of industrial dryers and textile machinery, has appointed L. A. Mitchell, Ltd., Manchester, England, to build Sargent-designed equipment for distribution in England and Europe.

Fischer & Porter Co., Hatboro, Pa., has been appointed by Gilbert & Barker Mfg. Co., West Springfield, Mass., as sales agent for the Gilbarco electronic tank gauge.

Chemical Engineering

Classified Section

JUNE 1957

For more information on the coverage, services or rates of CE's Classified Section, contact the McGraw-Hill office nearest you or write to Classified Adv. Div., Chemical Engineering, P. O. Box 12, New York 36, N. Y.

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▶ **Closing Date**—July issue closes June 3rd. Send new ads to Chemical Engineering, P. O. Box 12, New York 36, N. Y.

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Sales Engineer: Expanding New Jersey ceramic manufacturer of products used in the electronic, electric, and allied fields has opening on its sales staff. No selling experience needed. Write marital status, details of education, experience and salary desired. Replies held in strict confidence. P-5037, Chemical Engineering.

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Traveling Sales Manager Wanted by organization expanding on national basis. Graduate chemist, proven sales record in analytical instrument field and capable of earning in excess of $15,000. per year. Write or telephone National Spectographic Laboratories, Inc., 6300 Euclid Avenue, Cleveland, Ohio—UTah 1-4664.

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P-4920, Chemical Engineering
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Responsible for chemical equipment design and selection; construction scheduling; liaison between engineering, production and construction forces; approving design by contractor's engineering groups; and final field acceptance of completed installations.

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Salary commensurate with ability, experience, and education.

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Send complete resume of education and experience to:

P-5054, Chemical Engineering,
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P-4824, Chemical Engineering
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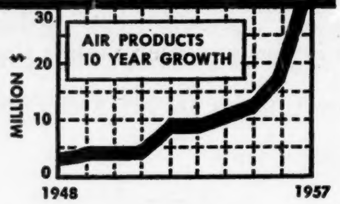

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Duties are: assistance in the preparation and analysis of basic information for design of operating units and supporting facilities in order to obtain optimum performance with minimum investment and operating costs; preparation of flow sheets; evaluation of process alternatives; selection and approximate sizing of equipment; and establishment of heat and material balances. Position requires five or more years of experience in equipment selection, economic evaluation of processes, and development of information for design of industrial facilities.

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BS in Ch.E or ME plus minimum of 10 years' experience in industrial water treatment: boiler feed, cooling water; ion exchange, supply procurement, boiler cleaning and inspection. Must have complete familiarity with boiler feed conditioning and waterside inspection. Experience in design of water treatment processes and power equipment helpful. Up to 3 years' in water supply procurement acceptable as partial substitute. Duties cover consulting and aid to Company plant, design and construction engineering personnel. Engineer should be mature, personable, articulate in speech and writing, able to assume responsibility in the field and coordinate activities of others. Must be free to travel.

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BS engineering or chemistry, minimum. 5-10 years' experience in plastics engineering for process equipment and auxiliary services. Duties include consulting services covering development, evaluation, selection, specification and fabrication of plastics for chemical process equipment and auxiliaries; investigations of failures and recommendations of remedial measures.

MATHEMATICIAN for Operations Analysis

Duties include: mathematical formulation of complex engineering and scientific problems in form amenable to numerical analysis; non-linear regression analysis of production data, using theoretical knowledge of chemical and engineering mechanism to select form of production equations; and development of applied methods to handle new industrial problems in matrix mathematics, numerical analysis, etc., being created by the availability of large scale digital computers. Operations are on a company-wide basis. Desired qualifications: a PhD or equivalent in mathematics or physical science with demonstrated interest in and experience with numerical analysis or machine computation.

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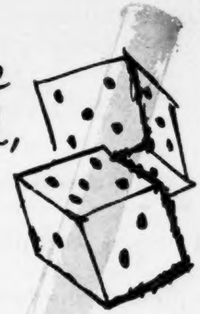

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REMINDER: get that letter in the mail . . . and get the facts!

Address Employment Supervisor, Dept. J-107

NATIONAL LEAD COMPANY
OF OHIO
CONTRACT OPERATOR
Fernald Atomic Energy Commission Project
P O BOX 158 MT HEALTHY STA
CINCINNATI 31 OHIO

TITANIUM METALS CORPORATION of AMERICA

FIRST IN TITANIUM

Announces immediate openings for:

DEVELOPMENT ENGINEERS
PROCESS CHEMISTS
PROCESS ENGINEERS
PROJECT ENGINEERS
RESEARCH CHEMISTS
RESEARCH ENGINEERS

TMCA is interested in men with degrees in Chemical, Metallurgical, Mechanical, Electrical, and Civil Engineering, Chemistry and Physics, to fill vacancies created by the expansion of titanium production facilities.

Opportunities in analytical development, quality control, process design, equipment design, process research, metallurgical research, and pilot plant operation.

Unlimited future, in this new and constantly expanding industry, for men with 0-10 years experience.

Salaries for these positions will be commensurate with ability, experience, and education.

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TITANIUM METALS CORPORATION OF AMERICA
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HENDERSON, NEVADA

To EMPLOYERS who advertise for MEN:

When there are many applicants for a single position it frequently happens that the only letters acknowledged are those of the most promising candidates. Others may not receive any indication that their letters have even been received by a prospective employer much less given consideration. These men often become discouraged, will not respond to future advertisements, and sometimes question their bona fide character.

Every advertisement printed in the Employment Opportunities Section is duly authorized.

It will help to keep our readers interested in this advertising if you wll acknowledge every application received, even if you merely return the letters of unsuccessful applicants with, "Position filled thank you" written or stamped on them.

We suggest this in a spirit of cooperation between employers and the men replying to Employment advertisements.

Classified Advertising Division

McGraw-Hill Publishing Co., Inc.

You wouldn't gamble where a career is concerned, would you?

Instead of "leaving it to chance," you would put the "I" in investigation! So...if interested in the Science of Tomorrow:

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sit down now and write us for the facts. Meantime, understand that

1. National Lead Co. of Ohio is the newest plant of its type processing uranium ores into nuclear reactor fuel elements . . . National Lead Co. operates the Atomic Energy Commission's Nuclear Feed Materials Production Center.
2. . . . possesses modern technical equipment and keeps abreast of latest scientific discoveries week by week.
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Chemists	•	Chemical Engineering
Metallurgists	•	Metallurgical Engineering
Ceramists	•	Physicists

REMINDER: get that letter in the mail . . . and get the facts!

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OF OHIO
CONTRACT OPERATOR
Fernald Atomic Energy Commission Project
P O BOX 158 MT HEALTHY STA
CINCINNATI 31 OHIO

CLASSIFIED . . .

EQUIPMENT SEARCHLIGHT

CE's Searchlight spots the big bargains in used, resale and rental equipment. Check this issue's listings — most complete in the field — for items you need now.

▶ **Coverage**—National (see index of advertisers in this section for your nearest dealer). Equipment and facilities—used, resale and rental—for the process industries. For sale, wanted for rent.
▶ **Rates**—$16.95 per inch for all ads except on a contract basis; contract rates on request. An advertising inch is measured ⅞ in. vertically on a column; 3 columns, 30 in. per page. Ads acceptable only in display style.
▶ **Closing Date**—July issue closes June 3rd. Send all new ads to Chemical Engineering, Classified Adv. Division, P. O. Box 12, New York 36, N. Y.

BIG SAVINGS IN GUARANTEED EQUIPMENT

DRYERS & KILNS
1—Stokes 2' x 6' Rotary Vac. Dryer.
1—Albright Neil 4' x 9' Atoms. Drum Dryer.
1—Buffalo Vac. Drum Dryer 24" x 20".
Vac. Shelf Dryers & Kilns.

CENTRIFUGALS & CENTRIFUGES
4—Tolhurst 40" Suspended Type Centrifugals.
8—Centrifugals 12", 30", 40", & 48" Steel, Copper, Stainless & Rubber Lined.
6—Sharples Centrifuges #5A Stainless, Also #6.
3—De Laval Multiple Clarifiers #200, 300 & 301.

FILTERS
#2 Sweetland Filter 12 Stainless Covered leaves.
1—Vellez 41 Stainless Covered Leaf Filter, types 49.
Ertel Eng 6 & 10 disc Filters 12¼" dia.
Sperry & Shriver 7" to 36 sq. in. Iron & Wood
Gen. Amer. 2" x 1" Rotary Vac. Filter.

KETTLES & TANKS
Pfaudler 200 gal. Glass Lined Closed Jack. Kettle.
1—Dopp 350 gal. C. I. Jack. Vac. Kettle.
Devine & Stokes Impreg. Units 30" & 36" dia.
Devine 1000 gal. closed jack. Steel Kettle.
1—2300 gal. Vert. agit. Jack. Steel Kettle.
8—Jacketed Kettles 50 to 2300 gals.
1—250 gal. Lead Lined Kettle.
Pfaudler 150 gal. closed agit. Jack. Steel Kettle.
50—Stainless Alum. Copper, Glass & Lead Lined Kettles & Tanks. Also new Stainless.

PULVERIZERS & MILLS
3—Mikro Pulverizers #2SI &2TH & Bantam.
Pebble Mills 24" x 30", 30" x 30", 30" x 34", 30" x 42", 4' x 5'. Also Jar Mills.
#1 Raymond Automatic Pulverizer 20 H.P. motor
1—Raymond #00 Pulverizer 30 H.P. Complete.
2—#0000 Raymond Mills.
Sturtevant #0 18" Hinged Hammer Mill.
Sturtevant Lab Swing Sledge Mill.
Jeffrey 18" x 18" Single Roll Crusher.
Day Hercules Spike Crusher 1½ H.P. motor.
Hammer Mills Pulverizers 3 to 50 H.P.
1—Shultz O'Neil 20" Pulverizers. Also #1.
Williams #3 & 2xx Hammer Mills.
1—Robinson 18" & 22" Attrition Mill.
1—Lehman 4 Roll W. C. 12 x 36" Steel Mill.
3—Steel 3 Roll Mills 9"x32", 12"x30" & 16"x40".
3—Houchin 18"x36", 4 Roll Granite Stone Mills.
Ball & Jewell Rotary Cutters Lab. & up.
2—U. S. & Premier 1½ H.P. Colloid Mills.

MIXERS & SCREENS
Day Imperial 75 & 150 gal. Jack. Mixers.
Baker Perkins double arm 50 & 100 gals.
2—Read 50 & 100 gal. double arm mixers.
Lancaster 6' dia. vert. Mixer 25 H.P.
Kent 3 H.P. Continuous Dry Mixer.
Horiz. Mixers single & double arm to 200 gal.
3—Day 8, 15 & 40 gal. Pony Mixers.
2—Day Brighton 20 gal. Change Can Mixers.
Read 40 and 80 qt. vertical Mixers.
6—Lead—Paste Mixers 50 to 150 gals.
Tyler 3'x5' Vibratory 2 Deck Screen. Other sizes.
Blystone 3000# horiz. spiral mixer.
10—Dry Spiral Mixers 50 to 3000#.
12—Portable Elec. Agitators ¼ to 5 H.P.

MISC. & SPECIAL
Stokes & Kux 2½" single punch preform machines.
Rotary & Single Punch Tablet Machines, ½" to 4".
Belt Conveyors 12', 15' & 20' long.
Anderson & French Oil Expellers.
Gould 75 H.P. Centrifugal Pump 250 PSI.
1—Marco 200 Stainless Steel Homogenizer.
Filling Machines powder, paste & liquid.
1—Howe Mogul Barrel & Bag Packer.
2—Worthington 12" x 12" x 12" Vac. Pumps.
6—Devine Stokes & Buffalo Vac. Pumps.
Soap Machinery for Toilet, Laundry, Chip, Liquid.
Plastic & Rubber Mills, Calendars, Hydr. Presses.
Inject. Mold Equipt. Extruders, Banbury Mixers.

NEW TANKS, STAINLESS & CARBON STEEL, BUILT TO YOUR SPECIFICATIONS
WE BUY YOUR SURPLUS MACHINERY & COMPLETE PLANTS
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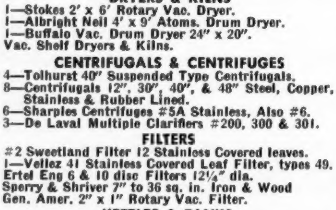

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Size "O" 8 gal. cap. Complete with one HP 3 vertical line 60 220-440 motor and new can as illustrated.

Price **$445.00** FOB Chicago.

Additional processing equipment in stock. Send us your inquiries and offerings.

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Almost New

PRESSURE FILTERS

Exceptional bargain on two 1500 sq. ft., horizontal, vertical leaf Pressure Filters. Ideal for assuring a supply of sparkling clear process water or similar applications. Steel construction; equipped with dual, vari-speed Milton-Roy filter-aid injection pumps. Spare leaves available. Appointment for inspection of one or both of these Filters can be readily arranged.

FS-4936, Chemical Engineering
Class. Adv. Div., P.O. Box 12, N.Y. 36, N.Y.

GOOD USED EQUIPMENT IN STOCK

Save Time! Save Money!

CENTRIFUGALS

1—AT&M Susp. 48" dia. Perf. Basket, St. St., Fume tight
2—Fletcher Susp. 40" dia. Basket, 1 perf. plain steel, 1 rubber covered imperf.
1—Fletcher 12" dia. St. St. Solid basket
3—Bird 24" x 24" Horiz. Centrifugal Screen Filters, Monel
1—Bird 24 x 38 monel, Solid Bowl
3—Bird 32 x 50 Solid Bowl Centrifugals, Type 316 Stainless Steel, fume-tight, 60 HP motor. Built 1953
1—Bird 36" x 50" Solid Bowl, Steel
1—Bird 40" x 60" Solid Bowl, T304 S.S.
4—DeLaval Nos. 74-11; 94-01; 600
2—DeLaval #BUH-3930 Hermetic Clarifiers, Stainless Steel
2—Sharples Super-D-Hydrators, C-20 & C-27, Stainless Steel T316

DRYERS

Mikro Pulverizers — Hammer Mills
Attrition Mills — Jaw Crushers
Comminuting Machines—Pebble Mills

Send us your inquiries—
write for detailed list

3—All stainless steel Vacuum Shelf Dryers, 108 sq. ft.
1—Devine #27 Vacuum Shelf, 475 sq. ft.
1—Devine #23 Vacuum Shelf, 356 sq. ft.
2—Devine Vacuum Shelf Dryers, size 17, 80 sq. ft. UNUSED.
1—St. St. Spray Dryer, 19' dia. x 20' high, with Western Precip. nozzles, fans, oil burners, etc.
1—American Double Drum Vacuum Dryer, 36" x 84"
6—Double Drum Dryers; 42" x 120"; 42" x 100"; 32" x 52"; 24" x 60"; 22" x 38"
4—Rotary Hot Air Dryers: 4'6" x 40'; 4'6" x 32'; 3'6" x 25"; 3 x 24'
3—Rotary Coolers: 104" x 30'; 104" x 70'; 5' x 40'
1—B & S Rotary Hot Air Dryer, 3' x 15', Everdur (Silicon Bronze)
2—Stokes Jacketed Rotary Vacuum Dryer 3' x 10', 3' x 15'
2—Rotary Steam Tube Dryers: Louisville 6' x 30' and Ruggles Cole 4' x 30'
2—Davenport size 2A Dewatering Presses
2—Swensen Walker Crystallizers steel, jacketed, each 30' long

EVAPORATORS—STILLS

1—Ozark-Mahoning Submerged Combustion Evaporator, type 316 stainless steel, 2,800,000 BTU/Hr.
2—Bartlett Snow, St. St. Jacketed Evaporating Kettles 6' dia. x 3' deep with heavy duty agitator and 25 HP 4-speed drive
1—Conkey 1,900 sq. ft. Triple Effect, Evaporator Vertical long Herculoy tubes
1—Buflovak size 6.5 model 629D Double Effect, all stainless steel, 588 sq. ft.
1—Stainless Steel Dairy type 6' dia. Vacuum Pan with coils
1—Struthers-Wells Single Eff. St. St. 625 sq. ft. vertical tubes
1—Stainless Steel 145 sq. ft. coil, 500 gal.
1—150 gal. Jacketed Vacuum Pan St. St.
1—Stokes type 316 St. St. Double effect water still, 250 GPH
8—Copper Bubble Cap Distillation Columns 24" dia. to 48" dia.
4—Stainless Steel Packed type Columns 8" dia. to 24' dia.

AUTOCLAVES—REACTORS

6—465 gal. St. St. 3' dia. 8'6" deep, 150# WP, 165# jkt. pr.
1—1420 gal. St. St., 4' dia. x 15' deep, 200# WP, 85# jkt. pr.
3—Pfaudler Glass Lined, jktd. & agit. 30 gal., 50 gal. & 100 gal.
3—St. St. T347 13 gal. 1400# test, 50# jkt.

FILTERS

1—Niagara Model 510-28-type 316 Stainless Steel Filter, 510 sq. ft.
2—Sparkler #33-S-28 Filters, Steel Tank, St. St. plates
1—Feinc 6'6" D x 6' Face String Discharge
2—Eimco 10' x 12' Rubber Covered Filter
2—Sweetland Filters: #12 (12 lvs.); #5 (20 lvs.)
5—Cast Iron Filter Presses, 30" x 30" open delivery, 28, 35, and 50 chambers
5—Filter Presses, closed delivery, 7"—36"
5—Louisville 36" wide 8-roll Continuous Filters

MIXERS—BLENDERS

1—Gemco St. St. 30 cu. ft., 54" dia., Jktd. Conical Blender
1—Conical Blender, Steel, 6' dia.
3—Sprout Waldron size 12 Ribbon Mixers, 336 cu. ft. work. cap.
5—Stainless Steel Sigma Blade double arm jacketed mixers, 3 gal., 5 gal., 10 gal., 50 gal. & 75 gal.
4—Sigma Blade Double Arm Jacketed Mixers, 2¼ gal., 50 gal. & 100 gal. work. cap.
1—Robinson 110 gal. St. Clad Jktd. Single Arm mass Mixer.
2—2,000 gal. Horiz. Jktd. Paddle Mixers
2—Side Entering Stainless Steel Mixers, 15 HP & 25 HP
3—Falk Vertical Agitator Drives #10-GDX, 10:1 300 HP—UNUSED
5—Turbo Vertical Drives, #5B, 5:1, 40 HP

MARCO FLOW MASTER UNITS
Stainless Steel
New in 1951—Expl. Pr. Motors

1—KACR Reactor, ser. #3127
1—Kom-Bi-Nator, 200 GPH, #3114
1—AC-500 Homogenizer, #3125
2—Roto-Feed Mixers, #3129, 3130
1—DP-Dry Proportioner, #3131

TANKS

2—Aluminum 18,000 & 24,500 gal.
10—Aluminum, 500 gal. 80# WP.
10—St. St. Pressure Tanks—to gal.
20—St. St. Storage Tanks—to 1000 gal.
1—St. St. Oval Tank, 2500 gal.
1—3,500 gal. St. St. Tank on trailer
1—600 gal. T313, ¼", ASME 15#
1—3000 gal. St. Clad Vertical Vacuum Tank with coils.
27—Vert. welded Steel Tanks, dished heads, 7500 gal.

STAINLESS STEEL HEADQUARTERS

USED EQUIPMENT IN STOCK—Tanks, Kettles, Receivers, Exchangers and Condensers, Stills, Agitators, etc.

NEW TANKS IN STOCK—From 30 gal. to 10,500 gal. sizes. Also large stock of prefabricated tank sections and heads to assure quick delivery of tanks.

CONVERTING EXISTING EQUIPMENT—(Your own equipment or our stock)—Can be done in our own shops utilizing surplus new or used materials on hand. HELIARC WELDING—Water Quenched Stabilized welds.

Equipment bought & sold

Plants Liquidated

BOTTLING CANNING MACHINERY PERRY SUPPLIES PROCESSING

PERRY EQUIPMENT CORP.

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$3,000,000 VALUATION
REAL ESTATE, MACHINERY & EQUIPMENT

Of The Former
TRENTON CHEMICAL COMPANY
TRENTON, MICHIGAN

By Order of the Board of Directors to be sold at

PUBLIC AUCTION

on THURSDAY, JUNE 20, 1957

Beginning at 10:30 A.M., E.S.T.

MAIN ITEMS

MONO SODIUM GLUTAMATE PLANT:—glass lined Reactors up to 2000 gals.; Stainless Steel Tanks from 500 to 3000 gals.; rubber lined Tanks; Bird 40" rubber lined Centrifugal; 2—AT&M 42" Stainless Steel Centrifugals; Bird 18x28 Continuous Centrifuges; Shriver & Sperry Filter Presses 30" and 36"; Arnold Single Effect Stainless Steel Evaporator, capacity 10,000# per hour; Stainless Steel Rotary Dryer; Stainless Steel Pumps; Olivite Pumps; Stainless Steel and rubber lined Piping, Valves and Fittings; 3—Fuller Compressors 25 HP; Laboratory; Copper and Stainless Steel Shell & Tube and Double Pipe Condensers; Raymond Mills; Pulverizers; etc.

EVAPORATOR PLANT:—Swenson Quintuple Effect Evaporator with copper tubes handling approximately 10,000 gal. of water per hour; 3—42"x120" American Double Drum Dryers; 3—Louisville 6'x50' Rotary Steam Tube Dryers; Bird 24" Continuous Centrifugal Filter; Louisville Dewatering Press; Spiral Dewaterers; Dryers; Screw Conveyors; Vibrating Screens; Hammer Mills; Mixing Tanks; etc.

BOILER PLANT:—4 Boilers, 1—528 HP Vogt, 1—419 HP Sterling, 1—298 HP Wicks, 700 HP Erie City, 175 to 200# pressure; complete coal handling and coal pulverizing equipment; Pumps; Compressors; motors; fans; piping; etc.

DISTILLERY & FERMENTING PLANT:—2—48" and 1—60" Copper Beer Stills; 2—48" and 1—60" Rectifying Columns; complete with Condensers; Piping; Copper & Stainless Steel Tanks up to 12,000 gals.; Weigh Tanks; Scales; 10—20,000 gal. Steel Fermenting Tanks and 22—22,500 gal. Steel Fermenting Tanks, some with Agitators; Digesters; 3—9'x27 Horizontal Steel Cookers; Centrifugal Pumps; Compressors; etc.

GRAIN HANDLING PLANT:—Large Steel Grain Bins; 5 Steel Grain Tanks 12'6"x47' high; Bucket Elevators; Screw Conveyors; Flour Mill equipment; Hammer Mills; Grain Dryers; Bagging & Weighing equipment; etc.

MISCELLANEOUS:—Steel Storage Tanks from 3 to 20,000 gal. capacity for oil and water; Air Compressors; Deep Well Pumps; Wood Storage Tanks; Centrifugal Pumps; motors up to 150 HP; large quantity of Piping, Valves, Fittings; Machine Shop equipment; Trucks; Tractors; etc.

REAL ESTATE:—12 Acres of Land with sidings on D.T.&I. and N.Y. Central Railroads; 10 Buildings with 130,000 sq.ft. of floor space, FULL DETAILS ON REQUEST.

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The Most Diversified Stock in the Equipment Industry

Zaremba Double Effect INCONEL Evaporator; 430 sq. ft.; accessories.

Shriver & Sperry Aluminum Filter Presses; 7", 12", 18" and 36".

Baker Perkins & W. & P. Heavy Duty Double Arm Jktd. Mixers; 100 to 300 Gal.

Hardinge Conical Ball Mill; 10' x 48".

Patterson Pebble Mills; 6' x 5'; 6' x 8'.

Whitlock S/S Heat Exchanger; 18" x 12'; 6 Pass; 204 Tubes; 420 sq. ft.

American Jktd.; Dbl. Door Sterilizers; Sizes up to 30" x 42" x 84"; welded.

Hersey Gas Fire Atmps. Dryer; 5' x 26"; Stainless contacts; accessories.

Send for Complete Inventory List

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BROOKLYN 15, N. Y.
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STAINLESS STEEL TANKS

IN STOCK

1—10,500 Gal. Horizontal T-304, Dished heads, 3/16" thick
1— 5700 Gal. Horizontal T-304
1— 3000 Gal. Vert.-mixing
1— 2800 Gal. Horizontal T-304
2— 2000 Gal. Vertical T-304
2— 1000 Gal. Vertical T-304
1— 675 Gal. Vertical T-304
5— 500 Gal. Vertical T-304

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Select from over 10,000 items

"BONANZA BUYS" FROM OUR LARGE STOCK

AGITATORS

8—Lightnin Model SEV 2500 side-entering 25 HP splash proof motors
1—Lightnin Model SEV 500 side-entering 5 HP splash proof motors
2—Lightnin Model SEV 300 side-entering 3 HP splash proof motors
4—Lightnin Model D-2 portable ½ HP exp. proof motors
4—Westbuilt new portable ⅓ HP gearmotors
6—Westbuilt new portable ⅓ HP 1750 RPM motors

CENTRIFUGES

1—Tolhurst 32" Suspended Rubber
1—A T & M 42" S.S. Suspended Perforated
1—Bird 48" Suspended steel. 25 HP
1—Sharples PY-14 Super-D-Cantor new, 316 stainless steel
2—Bird 18" x 28" cont. 316 S.S. solid bowl, 15 HP motor
1—Bird 32" x 50" cont. 316 S.S. solid bowl, 60 HP motor
2—Bird 40" x 60" cont. 304 S.S. 30 HP explosion proof motor
2—Sharples C-27 Super-D-Hydrators 316 S.S. 30 HP explosion proof
1—Delaval ACVO S.S. 20 HP motor
1—Delaval Model AAK1, 7½ HP motor
1—Podbielniak 316 S.S. PUP model

DRYERS & KILNS

1—Wyssmont R-32, Chemstone trays Everdur contact. New
2—Link-Belt Roto-Louvres, sizes 207-10; size 310-16
4—Rotary 5 x 50'; 6 x 60'; 7 x 54; 7½ x 45
1—Devine Vac. Shelf, 17 shelves 80" x 60" double door
1—American 36" x 84" double drum
1—Buflovak 42" x 90" double drum
1—Allis-Chalmers 6 x 7 x 100 Kiln
1—8 x 126' Kiln, ¾" shell
2—New Kilns, 4 x 30' and 4 x 60'

FILTERS

2—Niagara Model 510-28, S.S. leaves
2—Sparkler S.S. 14-D-4, 18-D-8
1—Sweetland #2, 9 lvs on 4" centers
2—Sweetland #7, with 41 leaves 2" centers, 20 leaves 4" centers
2—Sweetland #12, 46 leaves 3" centers, 30 leaves 4" centers
2—Oliver 3' x 2' Rotary Vacuum
1—Eimco 8' x 8' rotary. Continuous
2—Oliver 8' x 10' Continuous Precoat
2—Shriver 30" x 30" plate and frame, 32 chambers
1—Shriver 36" x 36", 20 frms 19 plates
4—Sperry 36" x 36", 60 recessed plates

MILLS AND MIXERS

1—Simpson Intensive No "O"
1—Baker-Perkins 16½ DIM sigma
2—Ribbons, 500# capacity, with 10 HP explosion proof motor
2—Stokes jacketed Ribbon, 30" x 36" x 8'
1—Raymond #1 Auto. Pulverizer double Whizzer Separator
1—Marcy 6' size 65 Ball Mill, 150 HP
1—Raymond No. 1 Imp. No motor
1—Raymond OO Pulverizer, 40 HP motor and cone separator
2—Charlotte S.S. Colloid, 2-3 HP
1—Charlotte Model 20 S.S. Colloid 20 HP
2—Micro-Pulverizers, 1—SH, 2—TH
1—Robinson 36" single runner Attrition, 100 HP motor
4—Williams 24" Hammermills, 60 HP
1—Fitzpatrick Model Comminuting
1—Williams 3 Roller Standard Mill with Cone Separator
1—Allis-Chalmers 15" x 30" Style "Q" Roll Crusher, New.
1—Buehler 10" x 20" 3 Roll Mill
2—Kent 12" x 32" 3 Roll Mill

SEPARATORS

1—Raymond 4' double Whizzer
1—Raymond 6' double Whizzer
4—Dorr-Clones, type 14" dia x 5' long, rubber lined
4—Krebs 5-B-10 Centriclones S.S., 10 HP
2—Sly #17 Dust Collectors, complete
1—Sly Bag House. Auto cont. 19,272 sq ft. Still in orig. crates

SCREENS

1—Selectro 18" x 36", single deck
1—Link-Belt, 24" x 48" single deck size NRM 124
1—Selectro 2' x 8' single deck
2—Selectro 4' x 10' Triple deck
2—New Tyler 4' x 5', S.S. Hummer
1—Abbe-Bluttergess Turbine, 3 HP.

MISCELLANEOUS

3—Condensers, pure nickel shell and tube, 300 sq ft area each
1—Conveyor, Conveyco vert. lift 12" Screw, 8' lift, 2 HP
1—Crusher, Penna. Reversible 350 HP motor, size 15" x 58"
2—Crystallizers, Swenson all iron bodies, 4' x 14', 300 sq ft area
7—Crystallizers, Swenson-Walker each 20' long, with individual drives
1—Evaporator, Majonnier, 60" dia S.S. coil type, 158 sq ft
1—Evaporator, 24" dia S.S. jacketed and agitated
1—Evaporator, 42" dia S.S. coil type, 11'5" overall height
1—Evaporator, Harris 6' dia S.S. coil type, 315 sq ft heating surface
1—Generator, Westinghouse 1200 KVA with Moore Turbine
2—Kettles, New Groen 60 gal. S.S. agitated Model RA
2—Kettles, new Groen 80 gal S.S. agitated, Model RA
4—Kettles, Lee 125 gallon S.S. jacketed 90#
3—Kettles Lee 250 gallon S.S. with steel outer jack, ASME 90#
1—Press, Valley, 16" dia S.S. twin screw, Model D342 continuous
1—Press, Stokes RB-1 Rotary Tablet 16 punch
1—Reactor, Pfaudler 500 Model gal. ELL
1—Sewing Machine, Union Special with extra head & Sack conveyor
1—Sterilizer, Wilmot-Castle, 36" x 42" x 84" long, double door
1—Tank, 2500 gallon, S.S. closed top and cone bottom
2—Tanks, 3000 gallons, S.S. 6' dia. x 18' long, closed
2—Tanks, 5000 gallon, S.S. closed with manhole

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Baker Perkins 50 gal. Steel and Stainless Steel Double Arm Jacketed Heavy Duty Mixers with Stainless Jacketed Blades.
3500 gallon working capacity Steam Jacketed Double Arm Mixing Tanks.
Day 4000 lb. Jumbo Dry Powder Mixer.
Stokes, Day, New Era, Hottman Mixers, from 2 to 450 gal., with and without Jackets, Single, Double Arm Agitators.
Baker Perkins, Day Readco Heavy Duty, 1 qt. to 160 gals., Double Arm Jacketed Mixers with Sigma or Fish Tail Blades.

LABELERS

Knapp Wraparound Labeler.
CRCO Nu-Way Wraparound Labeler.
Resina LC and Elgin Cappers.
Burt 611AUB Wraparound Labeler, to gal.
Pony M, ML, World, Ermold, Pneumatic Semi and Automatic Labelers.
Capem 4-Head Automatic Capper.

FILLERS

MRM and Elgin Rotary Fillers.
S. & S. G1, G2, G6, HG84 Fillers.
MRM S. A. Stainless Steel Vacuum Fillers.
Triangle Elec-Tri-Pak Fillers, 1 to 6 Head.
Elgin 5-Head, Hope 1, Filler 2 and 4-Head Stainless Steel Piston Fillers.

PACKAGING MACHINES

Pneumatic Scale Packaging Units with high speed Carton Feeders and Bottom Sealers, Weighers, Top Sealers with Compression Units, Carton Liners.
Transwrap Auto. Bag Machine.
Miller, Hayssen, Package Machinery, Oliver, Campbell, Transwrap Wrappers.
Standard Knapp 429 Carton Sealers.

GRINDING MILLS—SIFTERS

Fitzpatrick Model D Stainless Steel Comminuter.
Mikro 4TH, 3TH, 3W, 2TH, 1SH Pulverizers: Schutz O'Neill Mills.
Charlotte #3 Colloid Mill.
Day, Robinson, Tyler Hum-mer, Great Western, Gayco, Raymond Sifters.
Rotex Sifters—40½" x 120" and 40" x 84".

MISCELLANEOUS

Sparkler, Sperry, Shriver, Alsop Filters.

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Sharples C27 Super-D-Hydrator Type 316 STAINLESS; 30 HP XPL.

Sharples H2 Nozzlejector; Type DM with accessories; 15 HP XPL.

Bird 48" Susp. Rubber Cov. Centrifuge; fume tite; Plow Discharge; 40 HP 2 speed.

Bird Continuous Centrifugal Filter; 36"x50"; Stellited; 40 HP.

Bird Continuous Centrifugal with Solid Conical Bowl; 18" x 28".

A.T.&M. Susp. 40" Centrifugal; Annular Discharge; 15 HP.

Podbielniak Counter Current Solvent Extractor; Model 6070.

A.T.&M. 26" S.S. Centrifuge; under driven; perforate basket.

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Kady & Abbe S/S Dispersall Mills with motor
Pfaudler Glass Reactor, 20 gal., Jktd. & Agtd.
Pfaudler glass lined jacketed Still, 200 gal. new
3 Vibrating Sifters 20"x72", with motors
Hercules 200 sq. ft. SS Pressure Filter
AT&M 3'x6' Vertical Heavy Duty Mixers
Roto Louvre SS 5'x20' Rotary Dryer, complete
Nash Hytor Vac. Pump #6, with 40 HP motor
Pfaudler glass Kettle with S.S. ag't., 250 gal.
2 W&P Heavy Duty Jktd. Mixers, 15 gal., 15 HP
Gen. American 42"x120" Twin Drum Dryer
Ross 40 gal. Pony Mixer, direct drive, 3 H.P.
Sweetland #5 SS Filter, 20' leaves, on 3" cent.
Mikro Mill #2SI, serial #5403, extra head

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C20 Sharples Super-D-Hydrator SS
36" x 50" Bird Cond. Centrifuge
40" SS Bird Sus. Perf. Centrifuge
200 gal. B. P. West Churn jkt. vac.
Rotoclone Collector Size 36, Type W
3' x 14' x ¼" steel Column, 75 PSI
4' x 40' x 1-1/16" Steel Column
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5' x 20' x ¼" Rotary Cooler
7' x 50' x ½" Cooler
30" Robinson Rotary Cutter, 30 HP
Wyssmont Size Q24E Turbo Dryer
502-16 L.B. Roto Louvre Dryer
705-20 L.B. Roto Louvre Dryer, SS
705-24 L.B. Roto Louvre Dryer
6' x 50' Louisville Steam Tube Dryer
8' x 125' x ¾" Kiln

3'x15' STOKES 59B HERESITE LINED ROTARY VACUUM DRYER 7½ HP WITH COLLECTOR.

Screw-type Feeder 4CS B.P. SS
#10 Sweetland Filter 36-3" leaves
243D Stokes Oscill. Granulator
6' x 8' Abbe Ball Mill GPH, unlined
7' x 18' Patterson Ball Mill 2 Comp.
Jeffrey Hammermills, 15x8, 20x12
3620 DIXIE-Non Clog Hammermill
Micro Pulverizers 2TH & 1W
Case Packer Std. Knapp 6/1 gal. cans
412G Stokes Microvac (NEW)
300 gal. S.S. Jkt & Agit. Reactor
40" x 84" Rotex #41 Single Deck
60" x 84" Single Deck Rotex Screen
Gyro-Sifter Low Head 7 screens 1 HP
4500 gal. Hortonsphere
2500 gal. Rubber lined Tank 7' x 9'
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368 CFM	100 PSI	12x10 Ing.—Penn
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3—Bartlett & Snow 7'x30', 6'x30' direct heat Rotary.
1—Christie 70"x40' indirect heat Rotary.
3—Link Belt 5'2"x20', 6'4"x24', 7'5"x25'.
4—Devine double door Vacuum Shelf 17 and 20—59"x78" shelves.
3—Devine single door Vacuum Shelf 20, 19 and 18—40"x43" shelves.
6—Stokes single door Vacuum Shelf 4 and 6—24"x36" shelves.
2—Devine 5'x33', 4'x25' Rotary Vacuums.
1—Devine 5'x10' Rotating Vacuum.
1—Hersey 1½'x12' Rotary, 304 S.S.
3—Louisville Steam Tube 6'x50', 6'x35', 38"x25'.
2—Buflovak Atmospheric double drum 42"x120", variable speed drive.
1—Buflovak 5'x12' Atmospheric single drum.
2—Devine 4'x9' Atmospheric single drum.
4—Tray Dryers, steam heated, 95 sq. ft. tray area.

FILTERS

5—Sparkler 33-S-28, 150 sq. ft., 304 S.S.
1—Sparkler #14-D-4, 304 S.S. NEW.
2—Oliver Rotary, Monel 8'x10', 3'x?'.
1—Oliver 3' dia. Monel Horizontal.
1—Oliver 5'3"x8' Steel Rotary Vac.
1—Feinc 3'x1', Rotary Vac, 316 S.S.
1—Eimco 18"x12", 316 S.S.
2—Sweetland #12, 48 and 32 leaves.
1—Sweetland #7, 20 S.S. covered leaves.
1—Niagara #230-32, 230 sq. ft., 304 S.S.
3—Shriver 30" P&F, 36 chambers, iron.
2—Shriver, 30" P&F, 40 chambers, Heresite coated.

CENTRIFUGALS

5—Bird 32"x50" solid bowl Continuous Centrifuges 316 S.S. fume-tight, 60 HP, TEFC motors, NEW 1953.
2—Bird 36"x50", 18"x28" steel, solid bowl, continuous.
2—Bird 24"x38", 18"x28", 316 S.S. solid bowl, continuous.
2—Sharples #C-27, C-20, 316 S.S. Super-D-Hydrators.
1—Sharples PY-14, Super-D-Canter, 304 S.S.
2—Bird 40" suspended, 347 S.S.
1—AT&M 40" suspended, steel.
1—Bird 40" suspended, rubber.
3—Tolhurst 40", 32", 26", suspended.
1—AT&M 40" suspended, steel.
1—AT&M 36" center slung, rubber covered, perforated basket.
1—Tolhurst 32" Suspended, 304 S.S., perforated basket.

EVAPORATORS, REACTORS CONDENSERS, TOWERS, TANKS

1—Artisan 450 sq. ft., 304 S.S., single effect Evaporator, complete with piping, receiver, separator and condenser.
1—Nooter 1000 gal. nickel-clad, jacketed, agitated Reactor.
1—Glascote 500 gal. glass lined, jacketed, agitated Reactor.
2—Pfaudler 250 gal. glass lined, jacketed, agitated Reactors.
3—Pfaudler 500 and 300 gal. glass lined jacketed Reactors.
1—750 gal., 304 S.S. Kettle with coils and paddle agitator.
1—600 gal., 316 S.S. jacketed, agitated Reactor 200# internal pressure, 75# jacket.
2—500 gal., 347 S.S. jacketed Autoclaves or Reactors, 300# int. pressure, ASME.
3—500 gal., 316 S.S. closed, jacketed Tanks.
4—3500 gal., 304 S.S. jacketed, agitated Tanks.
1—Wyatt 18" dia. x 23', 316 S.S. Bubble Cap Column.
1—Wyatt 24" dia. x 42', 304 S.S. Bubble Cap Column.
1—10' dia. Hortonsphere, 225 psi.
1—10,000 Aluminum Storage Tank 10'x16'x½" shell, 25# W.P.
1—12,000 gal. Horizontal rubber lined Tank 10'6"x17'4".
5—1000 gal. S.S. Clad, Vertical Tanks.
1—Langenskamp 6'x5', 316 S.S. Vertical Tank.
2—Langenskamp 600 gal., 304 S.S. agitated Tanks with coils.
1—5'x6" dia. x 16' long, 304 S.S. Horizontal Tank, 3000 gals.
3—Steel Storage Tanks 8½'x25', 8'x16', 6'x20'.
1—Swenson-Walker 30', 304 S.S. Continuous Crystallizer.

HEAT EXCHANGERS

1—1665 sq. ft., 304 S.S. tubes, 75 psi.
1—1300 sq. ft., Admiralty Tube, 75 psi.
1—947 sq. ft., 304 S.S. tubes, 60 psi.
1—570 sq. ft., 304 S.S. tubes, 60 psi.
1—536 sq. ft., 304 S.S. tubes, 150 psi.
1—315 sq. ft., 316 S.S. tubes, 250 psi.
1—250 sq. ft., 316 S.S. tubes, 900 psi.
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3—Karbate 70.6 sq. ft., tubular.
2—Karbate 188 sq. ft., tubular.

PULVERIZERS—CRUSHERS

1—Dixie #3620 non-clog Hammermill.
4—NEW Jeffrey Hammermills 20"x12", 15"x18".
4—Hardinge Mills 4½'x16', 5'x22", 5'x36", 6'x22", 8'x48".
1—International 6'x7' poreclain lined Pebble Mill, 30 HP motor.
4—Patterson 6'x8', 5'x6', 3'x4' brick lined Pebble Mills.
1—Devine 5'x10' steel jacketed Ball Mill.
1—National 6"x12" Mill, Two Roll.
1—Kent 16"x14" Three Roll, High Speed Mill.
3—Gayco Air Separators 16', 6', 18".
3—Mikro Pulverizers, Bantam, #1SH #2DH, #2TH.
2—Ball & Jewell #1, #0 Rotary Cutters.

SCREENS

3—#34 Robinson Triple Deck 30"x104".
6—#42 Rotex Double Deck 40"x84".
3—#421 Rotex single deck 60"x84".
3—Robinson single deck 40"x84", 304 S.S.
1—Patterson single deck 40"x84", 304 S.S.
2—Tyler Hummer single deck 3'x5', 3'x10', 3'x15' with Thermionic Units.

MIXERS

1—Baker Perkins #15USE, ALL STAINLESS Double Arm, jacketed, Vacuum.
1—Baker Perkins #15VUMM, 100 gal. jacketed, 100 HP.
2—Baker Perkins #17DAM, 200 gal. jacketed, Sigma Blades.
1—Baker Perkins 100 gal., 304 S.S., Sigma Blades.
5—Day "Cincinnatus" double arm 250 and 100 gals.
1—Patterson 6' dia. Steel Conical, 15 HP motor.
5—Steel, jacketed, Powder 50, 225 and 350 cu. ft.
1—4' dia., 304 S.S., Conical, 3 HP motor.
1—Eppenbach 1 HP, 304 S.S. Homo Mixer.

MISCELLANEOUS

3—25 Ton Freon Refrigerating Units.
7—Stokes DD2, DS3, D3, B2, "R" & "F" Tablet Presses.
10—Nash Vacuum Pumps H7, H6, H5, L5, H4, TS7, #4, #2, AL-572.
2—Stokes #412G, 412B Vacuum Pumps, motor driven.
8—Wilfley 4" Haveg Lined Centrifugal Pumps, motor driven.
15—Chlorimet, Durimet and Duriron Centrifugal Pumps 1½" to 5".

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1—Stokes Stainless Steel Jacketed Rotating Vacuum Dryer, 6'x10' (New)

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AUTOCLAVES, KETTLES AND TANKS:

1—Stainless Steel Vertical Storage Tank, 9000 gallons
1—Stainless Steel Vertical Storage Tank, 4000 gallons
3—Stainless Steel Vertical Storage Tanks, 3000 gallons
3—Stainless Steel Vertical Storage Tanks, 1000 gallons
1—Van Alst Stainless Steel Jacketed Kettle, 600 gallons
1—Stainless Steel Jacketed Kettle, 600 gallons, complete with Turbo Agitator
1—Struthers Wells Type 347 Stainless Steel Autoclave, 1000 gallons, 2000# pressure
1—Pfaudler 500 gallon, Series R, Glass-lined Jacketed Reactor
1—Monel Jacketed Reactor, 200 gallons
1—Stainless Steel Jacketed Reactor, 200 gallons
1—Glascote 10 gallon Glass-lined Jacketed Kettle, 175 PSI Internal, 150 PSI Jacket
5—Pfaudler Glass-lined Vacuum Receivers, 30, 50 and 100 gallons (New)
1—Horizontal Aluminum Storage Tank, 18,000 gallons
1—Chicago Bridge & Iron Works, 17,000 gal. Pressure Tank, 80 psi

DRYERS & KILNS:

1—Allis-Chalmers Rotary Dryer, 7'6" x 64'
1—Buflovak Double Drum Dryer, 42" x 120", ASME Code
1—Stokes Double Drum Dryer, 5' x 12', complete, ASME
1—Hardinge Rotary Dryer, 5' x 50'
1—Hardinge Rotary Dryer, 7'6" x 55'
1—Bartlett & Snow Rotary Dryer, 4'6" x 36'6"
3—Link Belt Steel Roto Louvre Dryers, Models 207-10, 310-16 and 502-20

CENTRIFUGALS:

2—Sharples Type 316 Stainless Steel Centrifugals, Model D-2
1—AT&M Stainless Steel Suspended Type Centrifuge with 18" perforate basket, complete
3—Tolhurst Suspended Type Centrifuges, with 32" imperforate baskets, complete
3—Sharples Stainless Steel Super-Pressurite Centrifuges, Model 16Y
1—DeLaval Type 316 Stainless Steel Multimatic Centrifuge

FILTERS:

1—Baker Perkins Ter Meer Type 316 Stainless Steel Centrifugal Filter, Model HS-24"
1—Bird Continuous Centrifugal Filter, 24" x 38"
1—Sweetland #7 Filter with 20 leaves
10—Sweetland #12 Filters with 72 Stainless Steel leaves
1—Republic 15" Flexmaster Stainless Steel Filter, 15 chambers
2—Ertel Stainless Steel Filters, 12", 20 leaves
1—Oliver Rotary Vacuum Filter, Rubber-lined, 3' x 6'
2—Impco Rotary Vacuum Filters, Iron, 5' x 4', complete

MISCELLANEOUS:

5—Davis Eng. Type 347 Heat Exchangers, 120 sq. ft. (New)
5—Davis Eng. Type 347 Heat Exchangers, 200 sq. ft. (New)
2—Ross Steel Heat Exchangers, 1000 sq. ft. each
2—Stainless Steel Condensers 85 sq. ft. each
1—Stokes Model DDS2 Rotary Tablet Machine, complete
1—Stokes Model R Tablet Machine
6—Stokes Model F Tablet Machines
1—Foster Wheeler Dowtherm Unit, 600,000 BTU
1—Ames 500 HP Steam Generator, 125 PSI
1—Vulcan Steel Bubble Cap Col. 42" x 30', 20 trays, ASME (New)
1—Vulcan Steel Bubble Cap Col. 24" x 30", 20 trays, ASME (New)
1—Vulcan Steel Bubble Cap Col. 18" x 25', 18 trays, ASME (New)
1—Abbe Engineering Buhrstone-lined Ball Mill, 500 gal., Complete

2—Stokes Stainless Steel Jacketed Rotating Vacuum Dryers, 3'x10'
1—Wyssmont Model R32 Turbo Dryer (New)
1—Link Belt Stainless Steel Roto Louvre Dryer, Model 207-14
1—Vulcan Type 316 Stainless Steel Bubble Cap Column, 3'x41' with 30 trays

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222c *Hooker Electrochem. Co.

Aluminum Chloride......Methods for analysis of aluminum chloride are described in detail in 24 p. research report 11.57. Includes sections on reagents, indicators, standard solutions, precautions.
502A Allied Chem. & Dye Co.

Ammonium Thiocyanate ...... Product Bulletin 102, 4 p., covers ammonium thiocyanate as corrosion inhibitor for ammoniating liquors. Results of extensive laboratory tests are displayed in graphs and charts.
502B J. T. Baker Chem. Co.

Amyl Alcohol......4 p. bulletin F-8517C discusses physical properties, specifications, shipping data, uses and physiological properties of primary amyl alcohol. Most of the data is in chart form.
502C Union Carbide Chem. Co.

Benzyl Chloride......Bulletin BZYL 1-57 describes properties, storage and handling techniques of benzyl chloride. Also discusses uses in bactericides, fungicides, insecticides, preservatives.
502D Heyden Newport Chem. Co.

Bonding Agents......2 p. leaflet describes a line of rubber-to-metal bonding agents. Lists product names and suggested uses for eleven materials. Covers four series of cements.
502E Harwick Standard Chem. Co.

Catalysts......Catalog lists Girdler's full line of catalysts for hydrogenation, synthesis of gases and hydrogen generation, desulfurization, new catalytic processes. Send for Bulletin GC 1256.
191 *Girdler Co.

* From advertisement, this issue

LITERATURE

C. J. ROHRBACH

Catalysts, Platinum . . . . . . Baker-developed platinum metal catalysts are available in any required concentration of metal—on the carrier and in the form suited to your requirements. Request brochure.
347 *Baker & Co.

Chemical Specialties......Price list and catalog of 1,500 items on which company offers analytical reports via subscription. Reports provide quantitative and qualitative data on specialty items.
503A Chem. Specialties Labs.

Chemical Specialties......Aimed at building product specialty, waterproofing and paint manufacturers, new folder titled "How to Diversify Your Product Line" discusses four potentially profitable products.
503B Gas Purifying Prod. Co.

Chemicals......22 p. booklet lists company's line of industrial chemicals and pictures many of its facilities. Products include electroplating salts, fluorides, vinyl stabilizers. Send for your copy.
503C Harshaw Chemical Co.

Colloids......4 p. bulletin lists 44 colloidal and semicolloidal dispersions of graphite, molybdenum, disulfide, mica, vermiculite, zinc oxide, acetylene black, copper and glass. Physical data, uses.
503D Acheson Colloids Co.

Coloring Agents......12 p. brochure describes company's new line of vegetable coloring in the yellow-to-orange range offered commercially in both water soluble and oil soluble types.
503E S. B. Penick & Co.

Corrosion Inhibitor......"New Way to Solve Corrosion Problems," 4 p., describes a new corrosion inhibitor said to be effective with ferrous metals, aluminum and magnesium. Request your copy.
503F Virginia-Carolina Chem. Co.

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Contents of this issue . . .

LITERATURE . . .

Diisocyanates ...... Technical Bulletin I-17, 24 p., discusses typical reactions and suggested uses of company's line of diisocyanates. Includes a comprehensive bibliography with 132 entries.
504A Allied Chem. & Dye Corp.

Elastomers ...... Maintenance paints based on Hypalon resist ozone, oxidising chemicals, heat and weather, come in stable colors. Neoprene hose recovers original properties. Elastomers Notebook.
117 *E. I. du Pont de Nemours.

Epoxies......Describes this company's service in custom molding epoxy products. Covers compression and transfer techniques available for custom molding of electronic and chemical resistant products.
504B Epoxy Products, Inc.

Epoxy Resins......Bulletin EP-56-65 describes a new plastic material which can be cast in any thickness yet is said to possess the lowest shrinkage of any cast epoxy manufactured to date.
504C Furane Plastics Inc.

Essential Oils......12 p. brochure lists up-to-date wholesale prices on company's essential oils and other products including aromatic chemicals,, fixatives, colors, balsams gums, sundries.
504D Fritzsche Bros., Inc.

Ethylene Amines......8 p. bulletin No. F-8163A tabulates physical properties and specifications of ethylene amines. Describes their application in agriculture, chelating, polyamides; textile.
177 Carbide & Carbon Chem. Co.

Fluorides......Harshaw fluorides serve many industries. Their top ranking is the result of rigidly controlled uniformity and quality. Request Harshaw's book on hydrofluoric acid anhydrous.
210 *Harshaw Chemical Co.

Fungicide......"Fungitrol 50 For Colorless Non-Toxic Cordage Preservation" discusses a fungicide, a synergistic mixture containing zinc, which can be used from both water and solvent systems.
504E Heyden Newport Chem. Co.

Glycols......Diethylene glycol and triethylene glycol are discussed in new 16 p. bulletin F-8085. Data on physical and physiological properties, specifications, shipping containers, uses.
504F Union Carbide Chem. Co.

Graphite......4 p. catalog section S-5050 contains a large table recommending the grade of company's impervious graphite and resin base cement to be used in a wide variety of commercial applications.
504G National Carbon Co.

Industrial Cleansers......Catalog page describes a waterless hand cleaner and two protective hand creams for industrial workers. One cream counters kerosene, paints; the other guards against acids, bases.
504H Boyer Campbell Co.

Isophthalics ...... Brochure includes complete descriptions and detailed specifications of company's new isophthalic acid alkyds. Covers an unusual short oil alkyd which uses many new raw materials.
504I Reichhold Chemicals, Inc.

* From advertisement, this issue

Lithium......16 p. booklet defines a range of lithium chemicals in terms of their properties and unique aspects. Such uses as automotive greases, ceramics, air conditioning are discussed.
505A American Lithium Inst.

Methionine......Recent study reports evidence that methionine is beneficial to Vitamin C metabolism and to adrenal gland functioning. Methionine increased the Vitamin Cin the adrenal gland of animals.
71-2a *U. S. Industrial Chem. Co.

Ozone......Welsbach ozone is versatile in its applications and now in cost. Is finding more and more applications in industry. Used, for example, as an oxidant in the manufacture of cortisone. Booklet.
520 *Welsbach Corp.

Phosphates, Tributyl ...... Request sample, technical data sheet and information on utilization of TBP in brine-type refrigeration units and other heat exchange systems. Material available upon request.
175 *Commercial Solvents Corp.

Polyethylene......Offers new 14 p. brochure describing currently available grades of low molecular weight A-C Polyethylene. Gives actual and suggested end uses for these versatile polymers. Bulletin No. 116.
155 *Semet-Solvay Div.

Potash, Caustic ...... Offers: solid, flake, granular, broken, crushed, powder, walnut, at 90% strength; solid and flake, at 85% strength; liquid, low-chloride at 45% strength. Details in bulletin.
222e *Hooker Electrochem. Co.

Rauwolfia......First supplement to "Rauwolfia and its Alkaloids: A Bibliography" lists 223 additional literature references. They cover chemistry, pharmacology, pharmacognosy, therapeutic uses.
505B S. B. Penick & Co.

Refractories ...... Carborundum has pioneered scores of super refractories with a variety of properties to meet your most demanding requirements. For details, request "Refractories" magazine and bul.
221 *Carborundum Co.

Silicon......20 p. monograph, "The Relationship of Silicon and Its Properties to the Electronics Industry," covers rectifiers, solar batteries, transistors, vacuum tubes, semiconductors.
505C Aries Laboratories, Inc.

Silicones......New instructional leaflet outlines proper procedures for using silicone parting agents in shell molding. Discusses relative advantages and limitations of all types of agents. 4 p.
505D Dow Corning Corp.

* From advertisement, this issue

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LITERATURE . . .

Soda, Caustic . . . . . . Company offers Caustic Soda Engineering and Handling Guide, Bulletin 102; Caustic Soda Buyer's Guide. Bulletin 101 and technical data sheet. Company makes all available upon request.
222d *Hooker Electrochem. Co.

Sodium Dispersions......New 44-page bulletin on techniques and equipment for using sodium dispersions in pilot plant and full scale reactions. Higher yields, economy, new uses. "Sodium Dispersions."
71-2b *U. S. Industrial Chem. Co.

Sodium Metasilicate, Anhydrous...... Drymet anhydrous sodium metasilicate, when formulated with industrial cleaners and detergents, gives more soil-loosening and soil-dispersing power. File Folder.
B532 *Cowles Chemical Co.

Sodium Nitrite......Sodium Nitrite used, alone & in combination with other materials, for cleaning, neutralizing & protection of metals in diverse applications. "Sodium Nitrite for Rust & Corrosion Prevention."
179 *Solvay Process Div.

Sodium Sulfhydrate . . . . Hooker sodium sulfhydrate dissolves rapidly, even in cold water. There's virtually no sedimentation even after long standing. Available in 90-lb. & 350-lb. drums. Data Sheet.
222a *Hooker Electrochem. Co.

Sodium Sulfide......The clean, strong flakes dissolve right into process, even without stirring. No waiting-no decanting. For information on Hooker's sodium sulfide, request your Data Sheet.
222b *Hooker Electrochem. Co.

Surface Active Agents......New bulletin gives technical data on the seven types of surface agents offered by company. Basic formulations, data for testing effectiveness, storage and handling data.
506A American Cyanamid Co.

Surface Active Agents......12 p. brochure describes a new line of all-weather asphalt anti-stripping additives. Details on uses, test results. Products are cationic surface active agents.
506B Armour & Co.

Vinyl Plastisols ...... Portfolio titled "Plastisolutions to Your Finishing Problems" discusses potential uses for vinyl plastisol finishes in a 4 p. brochure. Also contains five data sheets.
506C Stanley Works.

Wax......New brochure describes company's line of microcrystalline waxes. Defines differences between paraffin waxes and microcrystalline. Surveys specifications in various grades.
506D Bareco Wax Co.

Zirconium......8 p. brochure, "More Zr Facts," discusses uses of zirconium's corrosion resistant properties in various types of atomic reactors and in chemical processing applications.
506E Carborundum Metals Co.

Zirconium......7 p. bibliography on applications and properties of zirconium and alloys. Covers mechanical, physical, electrical, chemical and nuclear properties, information on ore deposits.
506F Columbia-National Corp.

* From advertisement, this issue

Zirconium......12 p. illustrated booklet describes uses of zirconium and hafnium, their mechanical and physical properties and company's sodium process for producing the metals. Fabrication data.
507A U. S. Industrial Chem. Co.

Construction Materials

Concrete...... Brochure, "Permanent Repair and Restoration of Cracked and Spalled Concrete and Other Masonry Structures," instructs on how to use epoxy-based industrial polyplastic alloys.
507B Permagile Corp. of Amer.

Concrete, Pre-Stressed......New 4-page bulletin describes design and application advantages of pre-stressed concrete for the construction of storage tankage, fire walls, butane or propane storage vessels.
507C Preload Co.

Coatings......There are three Norton Rokide coatings: Rokide "A" aluminum oxide, Rokide "ZS" zirconium silicate and Rokide "Z" stabilized zirconia. Proved in such applications as reaction motors.
201 *Norton Co.

Coatings, Masonry ...... Insul-Mastic offers six types of coatings which provide economical solutions to many masonry problems. These coatings come in white, clear and colors. Write for information.
83d *Insul-Mastic Corp. of Am.

Coatings, Mastic......Insulating mastics with new Fire-Redtrdant insulate a metal surface against reaching 1000 degrees F. for 30 minutes under 2000 degrees F. flame. Longer lasting, stable protection.
83a *Insul-Mastic Corp. of Am.

Coatings, Poly-Ply......Poly-Ply is a safe, simple and lasting way to coat, line and repair industrial equipment. It is applied cold. Insul-Mastic Corp. offers full information on this product.
83c *Insul-Mastic Corp. of Am.

Coatings, Protective......4 p. bulletin describes a coating designed to solve home maintenance problems, said to be suitable for exterior and interior use and to be both weatherproof and waterproof.
507D Tuff-Kote Co.

Coatings, .Protective......Catalog describes Amercoat protective coating systems for corrosion control. Outlines corrosion control services: assistance in selection, help write specifications, etc.
423 *Amercoat Corp.

Coatings, Protective......Color-Coat is a lasting color finish for Insul-Mastic protective coatings and concrete, brick, cinder block, metal trim, porous roofing tile, asbestos shingles, stucco, etc.
836 *Insul-Mastic Corp. of Am.

Coatings, Protective......Tygorust & Tygon "ATD" are companion products to make your fight against corrosion less costly—more effective. You can get better protection. See "Tygon Painting Manual."
136 *U. S. Stoneware Co.

*From advertisement, this issue

LITERATURE . . .

Construction Materials, Accessory...... Insul-Mastc Corp. supplies a full line of caulking compounds, mastic and weathersealing cements, primers, thinners, and aluminum spray. Send for your information.
83e *Insul-Mastic Corp. of Am.

Fabrication Metal......"Facilities & Products," with information & photographs which show why company can turn out—at low cost—specialized heavy equipment for chemical plants, available on request.
126 *Newport News Shipbuilding.

Fabrications, Plastic ...... American Agile, a pioneer in the field of fabrication and welding of polyethylene and polyvinyl chloride, has experience, specialized skills, production facilities. Brochure.
522 American Agile Corp.

Laminates, Low Pressure......Bulletin covers low pressure laminates for corrosion resistance, electrical insulation, high strength and unlimited shapes. Company offers further information.
508A Carl N. Beetle Plastics

Metals, Talide......Tungsten carbide of superior quality, is harder, stronger, and more resistant to abrasion than and other metal. Superior where wear, heat and strain are destructive. Catalog 56-G.
98 *Metal Carbide Corp.

Porcelain Enamel ...... Porcelain Enamel in Industry tells about the advantages and unique features of porcelain enamelling. Common uses mentioned include meter dials, Instruction plates, oil-seal shoes.
508B Erie Ceramic Arts Co.

Rubber & Plastic Materials......Piping pumps, valves and tanks have a wide range of temperatures, pressure, impact resistance. For details about Ace rubber and plastic materials, request Bull. CE-50.
365e *American Hard Rubber Co.

Steel, Plastic......Devcon is a plastic steel which is 80% steel and 20% plastic. Use Devcon for metal forming and for lathe fixtures, for holding irregular pieces, etc. Request Bulletin N1-101.
508C Devcon Corp.

Steel, Stainless......A 40-page booklet "Stainless Steel Report to the Textile Industry" gives detailed information on the textile industry. One section deals with corrosion resistance to textile media.
508D Allegheny Ludlum Steel

Steels, Corrosion-Resistant......Details on the application, corrosion-resistance, properties and workability of Carpenter alloys B and C are found in a bulletin now available from the supplier.
508E Carpenter Steel Co.

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Steels, Stainless......Company offers informative 44 p. booklet, "Making the most of Stainless Steels in the Chemical Processing Industries." Dozens of Crucible stainless grades are available to you.
123 *Crucible Steel Co. of America.

Steels, Stainless......Wide selection of carbon, alloy and stainless steels in bars, structurals, plates, strip, sheets, tubing, reinforcing products, industrial plastics, tools, machinery, etc. Catalog.
234a *Joseph T. Ryerson & Son.

Steels, Stainless, Aircraft......Ryerson manufactures stainless steel bars, sheets, strip, and plate to U. S. Government and Aeronautical specifications. Send for Ryerson Aircraft Steels booklet.
234b *Joseph T. Ryerson & Son.

Titanium...... Shows resistance to chloride solutions and retains useful strength up to 800-1000F. Other advantages and data on application and fabrication of titanium alloys in Rem-Cru Review.
48-9 *Rem-Cru Titanium.

Varnish, Epoxy......Bulletin discusses Alliseal epoxy varnish L. A. V6250—tank life and shelf life, thermal endurance, resistance to contamination, mechanical strength, good varnish practice, etc.
509A Louis Allis Co.

Varnish, Insulating......Bulletin discusses Alliseal clear heat reactive insulating varnish L.A. V6350—tank life and shelf life, thermal endurance, resistance to contamination, mechanical strength, etc.
509B Louis Allis Co.

Zirconium......Company's new, zirconium publication, "More Zr Facts," is designed to provide the first continuing source of zirconium technical data to industry. Place your name on the mailing list.
349 *Carborundum Metals Co.

Electrical & Mechanical

Batteries......You'll find the full story on Goulds new "Thirty" industrial truck battery in Bulletin GB1567B. It gives full construction details, and engineering specifications for three sizes.
509C Gould-National Batteries.

Bearings-Bushings-Washers...... Chempro's new Style FM-4 bearings, bushings, washers, etc., give service in pumps, mixers and reactors operating under corrosive conditions. Details in Bulletin CP554.
L546 *Chemical & Power Products.

Drives, Worm Gear......New 16-page illustrated brochure, "Finger Tip Facts on Cleveland Worm Gear Drives," provides useful summary information on complete standard line of speed reducers, worm gear sets.
509D Cleveland Worm & Gear Co.

Fastenings...... 150,000,000 standard fastenings-bolts, nuts, screws, rivets, washers, are ready for immediate delivery. Results of independent laboratory tests prove superior strength. Form No. 126.
362 *H. M. Harper Co.

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Fastenings, Corrosion-Resistant......Harper Flo-Form Process employs highly special techniques to produce parts of economic design, with greater strength and durability, without scrap loss. Flo-Form Cat.
363 *H. M. Harper Co.

Floodlighting, Mercury Vapor......How you should use mercury-vapor floodlighting, together with technical information for evaluation, is contained in 16-page bulletin, "Mercury Vapor Floodlighting."
510A Crouse-Hinds Co.

Gaskets......Chemiseal teflon jacketed gaskets for standard flanges and glass-lined steel connections and for corning conical flanges, also reducers. Company gives details in Catalog No. AD-154.
361b *U. S. Gasket Co.

Motors......Complete condensed motor catalog covers: cross reference between old and new NEMA ratings both hp and dimensions; current pricing for 1/20 through 1000 hp; standard motor modifications.
505 Marathon Elec. Mfg. Co.

Motors, Chemical ...... New motor specifically designed and constructed to withstand corrosive conditions encountered in chemical plants, oil refineries, sulphur plants, etc. See Bulletin 1050.
424 Louis Allis Co.

Motors, Electric......New line of L.A. open drip-proof motors feature: modern styling, improved lubrication, greater protection, dependable insulation, etc. For complete details, see Bulletin 1700.
510B Louis Allis Co.

Motors, Electric......Wagner Increment Motor-Starter Combinations provide low cost control, meet the polyphase motor starting recommendations of the AEIC-EEI-NEMA. Write for Bulletins MU-128 and MU-195.
455 *Wagner Electric Corp.

Motors, Weather Protected......Features which contribute to the outdoor dependability of Type FOD weather-protected motors in ratings from 250 to 900 hp. are discussed in Bulletin 51B8606A.
510C Allis-Chalmers Mfg. Co.

Motors, Weather-protected......Newly designed weather-protected motors need no protective enclosures, provide ventilating system, removable air ducts, stator assembly. Bulletins 51B8606A, 05B7894.
90 *Allis-Chalmers Co.

Packings, Mechanical......In Bulletin P-325 you'll find complete service and technical details on chemically inert mechanical packings fabricated from Teflon. Includes specific recommendations on applications.
510D Crane Packing Co.

Packings, Ring......Chemlon Teflon packings solve your corrosive and toxic liquid problems at temperatures from −120 degrees F. to +500 degrees F. without fear of product contamination. Bulletin P-325.
385 *Crane Packing Co.

Packings, Teflon......"Teflon" is used because it is impervious to industrial acids and caustics; has no known solvent; has zero water absorption; is unaffected by weather. "Teflon" Accessories booklet.
392 *Raybestos-Manhattan.

* From advertisement, this issue

Potentiometers, Transmitting......Bulletin describes Series 184A transmitting potentiometer pyrometer and Series 184E transmitting potentiometer millivoltmeter. Full details in Bulletin MTT810.
511A Manning, Maxwell & Moore.

Seals, Mechanical, Rotary......Company announces the availability of an 8 p. reference which shows how you get maintenance-free sealing that slashes fluid mixing cost to a new low. Bulletin B-111.
321g *Mixing Equipment Co.

Transformers......Written for industrial maintenance people, booklet "Timely Tips on Transformer Maintenance" covers general inspection procedures, classification, drying out and connections.
511B Westinghouse Electric Corp.

Handling & Packaging

Bag Packer......Newest Kraftpacker automatic open-mouth-bag filling machine described in a new brochure accommodates weights from 25 to 200 lb. Users report average rate 18 bags/min. for full-days runs.
511C Kraft Bag Corp.

Belts, V......How you can prolong belt life, increase drive efficiency and assure full continuous production are told in new 12-page bulletin 20X6234C, "Longer Belt Life for Your V-Belt Drives."
511D Allis-Chalmers Mfg. Co.

Belts, V......"What do you do when V-belts stretch or break" poses and answers questions on V-belt maintenance, inventory, wear and vibration. The four-page folder features Veelos adjustable-link V-belting.
511E Manheim Mfg. & Belting Co.

Containers, Bulk......How you can save by shipping chemicals in corrugated bulk containers is discussed in a new 4-page brochure. Included are case histories of successful chemical industry uses.
511F Gaylord Container Corp.

Conveyor, Belt......Bulletin on Tru-Trak steel belt conveyor explains and illustrates how V-ropes bonded to the underside of steel conveyor belts travel over grooved sheaves to maintain belt alignment.
511G Sandvik Steel

Conveyors......Several new engineering advances in flow equipment are featured in a new materials handling equipment catalog. Look for hydraulically controlled portable power belt conveyor and others.
511H Speedways Conveyors.

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Conveyors......Standard designs and builds permanent and portable systems and units, using roller, belt, slat, chain, pushbar or sectional conveyors—power or gravity. Spiral chutes, etc. Bulletin 0-6.
502 *Standard Conveyor Co.

Hooks......Rugged, flexible hand-tool that works around corners and obstructions to remove old packing from stuffing boxes. All steel, tempered steel corkscrew bit, six sizes. Dura Hook Bulletin CEDI.
B531 *Durametallic Corp.

Loaders......S-A Standard and "Hi-Type" SWIVELOADERS in Catalog 854, S-A Box Car Loader in Catalog 948, full line of materials handling products ready for immediate shipment in Catalog 60.
421 *Stephens-Adamson Mfg. Co.

Loaders, Tractor......Compact Tractomotive TL-6 Tractor-Loader quickly unloads boxcars, travels through narrow isles and doorways, makes hairpin turns around columns and posts. Request product bulletin.
73 Tractomotive Corp.

Pulleys, Welded Conveyor......In Bulletin 5781 are described welded steel conveyor pulleys for belt conveyor and bucket elevator systems. Included are drum types and self-cleaning wing types.
512A Chain Belt Co.

Scales......Howe Scale Catalog No. 11 is a handy reference featuring the popular scales from the complete line of standard Howe scales. Includes specifications and spot illustrations.
512B Howe Scale Co.

Scales.....New Toledo Weight Fact Kit will help you determine how well your scales measure up as a weighing system and help you detect weighing inefficiencies that drain profits. Send for it now.
406 Toledo Scale Co.

Scales, Railroad track......You get all modern "plus" features in Howe four-section straight lever railroad track scale—lever system, main bearings, checking, live and dead rails, etc. Form 685.
512C Howe Scale Co.

Tanks, Oil Storage......In the newly revised bulletin "Oil Storage Tanks" you'll find descriptions of standard sizes, types of roofs, welding, testing, maintenance and dimension tables.
512D . Chicago Bridge & Iron Co

Truck, Fork......Design, operation and advantages of the Clarklift-30 gas-powered 3,000-lb. capacity fork truck are covered in a new 6-page brochure that also includes information about components of truck.
512E Clark Equipment Co.

Trucks, Electric......Lewis-Sheppard Electric Trucks enable full use of floor storage, provide mobility between departments, work quickly and safely, cut manpower costs. Master Line Cat. and Cat. 34-1.
405b *Lewis-Shepard Products.

Trucks, Electric Fork....New "E" model electric fork truck—electric power gives 3 times longer life than other type trucks, lubricated-for-life, only 50¢ a day for battery charging, magnetic controls. Cat. 32-1.
405a Lewis-Shepard Products.

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JUST OUT! In this book **scores of experts** give you all the workable facts, methods, and techniques you need for better plant maintenance—for lower production costs, higher profits, and improved product quality. From the organization and administration of maintenance forces to sanitation, welding, and corrosion control you have the complete, detailed picture. **Edited by L. C. Morrow, Dir., Spec. Editorial Services, McGraw-Hill Pub. Co. 1156 pp., 728 illus., $20.00**

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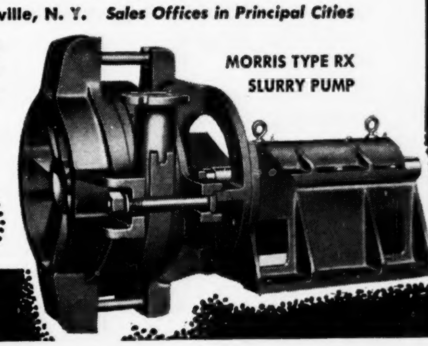


Trucks, Fork......The four major components of electric fork trucks—control circuit, power train, hydraulic system and upright assembly—are described in a new 8-page four-color brochure.
514A Clark Equipment Co.

Trucks, Gas....Powerful Yale gas truck with new Yale hydraulic push-pull attachment stacks nitrate bags with maximum ease, safety and efficiency onto a pallet for shipping. Full facts in Booklet 5101D.
105 *Yale & Towne Mfg. Co.

Trucks, Lift......Facts on a complete line of manually propelled, battery operated hydraulic lift trucks are gathered in a new illustrated 24-page catalog. Concept of In-Between Handling is explained.
514B Big Joe Mfg. Co.

Heating & Cooling

Boilers, Packaged......Bros packaged boilers fulfill steam requirements in the medium pressure range Offer high steam generating efficiencies with economy of installation. Bros Packaged Boiler. Cat. WT-10.
396 *Wm. Bros Inc.

Cleaner, Steam......Complete steam cleaning facilities are provided for a fraction of the usual cost with the Steamrette according to a 4-page bulletin now available from the manufacturer.
514C Turco Products, Inc.

Cooler, Rotary-Louvre......Four-page bulletin describes features of new cooler design where the louvers that move the solids are hollow to permit the flow of cooling water counter to the material flow.
514D Dunford & Elliott Eng'g.

Condensers, Surface......Sweco surface condensers offer maximum de-aeration, even distribution of steam, increased efficiency of heat transfer, compact installation, servicing accessibility. Bul. M-3-32.
528 *Southwestern Engineering Co.

Condensers, Vapor......Contains diagrams and photographs showing apparatus for condensing vapors independent of a large supply of cooling water. For details on Aero vapor condensers, see Bulletin 129R.
R519 Niagara Blower Co.

ElectroSyn System......Highly flexible, rugged electro-magnetic system designed to measure, indicate, record or control pressure, differential pressure, flow, liquid level, temperature. Technical Bul. B257.
79 *Norwood Controls.

Furnaces......For batch heating oils, chemicals, resins, varnishes, inks. Selas Duradiant enclosed or open settings offer fast, radiant gas heating, rapid burner response, and uniformity. Bulletin SC1015.
42-3c Selas Corp. of America.

Generators, Steam.....Amesteam generators give extra years of service Rugged construction exceeds code requirements; simple, efficient 3-pass concentric tube design. Request your catalog.
111 *Ames Iron Works Inc.

* From advertisement, this issue

Generators, Steam......Book gives capacities, dimensions, construction features, instrumentation, accessories, sectional drawings & installation photos on new series of steam generators. Bulletin PG-55-3.
333 *Foster Wheeler Corp.

Heat Exchange & Process Equipment......Company offers these: condensers, evaporators, jacketed kettles, ribbon mixers, agitators, reactors, pressure vessels, heat exchangers, etc, Bulletin 810.
T534 *Manning & Lewis Engrg.

Heat Exchangers......Advantages of Whitlock Standards Hi-Transfer units include low cost, engineered design, interchangeable parts and units, non-ferrous construction, easy maintenance. Bulletin 170.
417 Whitlock Mfg. Co.

Heat Exchangers, Acid Resistant......Important data on Swenson type of tube mounting, types or corrosion resistant materials and advantages of neoprene ring gaskets available in Bulletin SW-200.
337 *Swenson Evaporator Co.

Heat Transfer Equipment......Partial list of material processed with A-C heat transfer equipment: limestone, lime, dolomite, magnesia, alumina, bauxite, manganese oxide, iron ore, etc. Bul. 25C6177.
197 *Allis-Chalmers Mfg. Co.

Heat Transfer Units.....Valuable ideas based on installations of Tranter Platecoil heat transfer units are contained in bulletin on Platecoil construction, installation and cost-saving advantages. Bul. P-61.
106 Tranter Mfg.

Heaters, Dielectric......Shorter processing time maximum production per unit of floor space, streamlined work flow, minimum heat loss, improved working conditions, simplified operation. Bulletin 15B6431C.
225 *Allis-Chalmers Co.

Heaters, Gradiation.....Advantages include zones of controllable heat input, complete combustion, uniform application of heat, and shop-assembly or field-erection as desired. Bulletin S1043.
42-3a *Selas Corp. of America.

Heaters, Steam......In catalog 956 you'll find complete information about the Grid cast-iron heat transfer units. Includes descriptions of manufacturing, installation and piping; calculating aids.
515A D. J. Murray Mfg. Co.

Heating Elements......First authoritative book of its kind, 12-page booklet Form A-1472 gives information on handling, unpacking, storage, installation and replacement of silicon carbide elements.
515B Carborundum Co.

Ovens......Despatch Electric V-35 Production Ovens can bake plastic items and bake standard and wrinkle finishes on metal parts for other products. Automatic temperature control. Get V-Bulletin.
T540 *Despatch Oven Co.

Thermo-Panels......Cost less and perform better—an improvement on pipe coils. Save space and heat or cool more efficiently. For use in heating and cooling of liquids, slurries, etc. Bulletins 355 and 257.
TL553 *Dean Thermo-Panel Div.

* From advertisement, this issue

Tower, Cooling...... Illustrated brochure shows features of Galloway counter-flow cooling tower that make possible a 5-year warranty. Tower is non-leaching Chemonited Douglas Fir which resists fungus.
516A G. W. Galloway Co.

Towers, Cooling......New catalog section III, File 3D3, Sheet 1 tells the user facts about maintenance of redwood cooling towers. Includes types of deterioration, and how to control and prevent it.
516B California Redwood Asso.

Towers, Cooling......If you would like to know the Marley method of measuring performance of cooling towers, regardless of make or vintage, request "Test Your Tower." Assurance of complete satisfaction.
9 *Marley Co.

Trap, Steam......Catalog 600 announces development of the Mono-valve float-thermostatic steam trap designed to drain steam-hot condensate. Unique feature is single valve that performs three jobs.
516C Velan Valve Corp.

Traps, Steam......Within 4-page Bulletin 154, you will find a complete condensed buying guide on steam traps containing specifications, capacities, sizes, pressures, weights and list prices.
516D V. D. Anderson Co.

Traps, Steam......New Bulletin T-1746 describes the new Series 40 impulse steam trap designed especially to handle heavy condensate loads. The 4-page bulletin gives sizes, capacities, applications.
516E Yarnall-Waring Co.

Traps, Steam......Armstrong Steam Trap Book contains helpful information on steam trap safety factors providing for venting of gas, peak loads, reduction in pressure differential, group trapping.
93 *Armstrong Machine Works.

Traps, Steam......Give faster, more effective condensate removal. Powerful valves action, positive shut-off, high capacity & each unit service tested. For more details, request new Bulletin No. 10-55.
82 *W. H. Nicholson & Co.

Traps, Steam.. ..Yarway Series 40 impulse steam traps are ideal for heavy condensate loads on large autoclaves, cooking kettles, heat exchangers, dryers, heating coils, presses, etc. Bulletin T-1746.
427 Yarnall-Waring Co.

Instruments & Controls

Annunciator Systems.......New 32 p. catalog describes the complete line of standard, integrated Panalarm Annunciator Systems for industry. Company makes full details available in Catalog 100B.
L536 Panellit, Inc.

Computer......A 12-page brochure describes the new completely transitorized computer Transac type S-2000. Using only air cooling and negligible power this light-weight system cuts installation costs.
516F Philco Corp.

* From advertisement, this issue

Control Systems, pH......Data sheet discusses L&N pH Control System—electrode assembly, Speedomax recorder, Control Unit, Valve Drive. Complete details in Process Data Sheet 700(2).
132 *Leeds & Northrup Co.

Controller, Draft......For the first time adjustable proportional band is available in draft controllers for commercial and small industrial plants according to a 4-page bulletin just released.
517A Cleveland Fuel Equipment Co.

Controllers.....Features the M/58 Controllers revolutionary floating disc system—the exclusive design development that gives M/58 Control its unique versatility, precision, stability. Request Bulletin 13-19.
54-5 *Foxboro Co.

Controllers, Pneumatic......Bristol Series 500 models for control of temperature, pressure, vacuum, draft, absolute pressure, liquid level, flow, humidity, density, pH, and other variables. Bulletin A130.
60-61 *Bristol Co.

Controllers, Pyrometer.....Multi-Point, Pyrometer Controller provides—in one instrument—automatic temperature control for up to ten separate process units. Company gives information in Bul. EDS-25-E.
529 *Thermo Electric Co.

Controls, Electric ...... Automatic "package" controls are discussed in a new 16-page catalog AC-2. They are used for applications where a chemical or mechanical function can be measured electrically.
517B Tipp-Tronic, Inc.

Controls, Pressure......Three bulletin pages cover pressure controls—Type H5 in Bulletin 5-5; Type J7 in Bulletin 5-7 and Type J40 in Bulletin 5-9. Cover specification policy, purpose, switch ratings, etc.
517C United Elec. Controls Co.

Controls, Temperature......17 p. catalog presents company's line of remote bulb temperature controls . . . industrial, aircraft, marine, special purpose. Includes features, specifications, etc. Catalog Sec. 200.
360 *United Elec. Controls Co.

Controls, Temperature......Features: cuts initial control costs; costly production stoppages; control maintenance costs. Controls for gas, liquids and solids in −30°F. to 1200°F. ranges. Condensed Catalog.
518 *Partlow Corp.

Flowmeter......Catalog sheet RC-1 relates how the vortex-velocity principle of flow measurement has been designed into a compact liquid flowmeter that is self-contained and reads from 20 to 220 gpm.
517D Rotron Controls Corp.

* From advertisement, this issue

Any bulletin or catalog . . . yours for the asking

You can get any publication in this literature listing by circling its key number on the Reader Service Post Card (inside back cover). Replies will reach you direct from the manufacturers.

Flowmetering Systems, Electronic...... Potter Flowmetering Systems are highly accurate throughout a wide range of temperature, pressure, density and viscosity conditions. Write for Bulletin CE-6.
207 *Potter Aeronautical Corp.

Flowmeters...... Series 1700 Flowrator meters in more than 20 materials with stainless steel enclosures, neoprene backed up to 200 gpm of water, 400 scfm air. Cat. 10-A-25.
161 *Fischer & Porter Co.

Gages......U. S. Gauge Division offers catalogs of Supergauge, Solfrunt (Solid Front) Gauge for maximum safety, Diaphragm Receiver Gauge and Pressure Pilot, all designed for optimum process efficiency.
397 *U. S. Gauge Div.

Gages, Pressure & Vacuum...... Company gives details available on its dial indicating and recording pressure and vacuum gages. SG safety gage feature affords safety in front and back. Bul. 525A.
BL547 *Weksler Thermometer Corp.

Indicator...... Leaflet announces a new Teledyne instrument to indicate telemetered information from strain gage type transducers. Precision d.c. meter movement and power supply excite measuring circuit.
518A Taber Instrument Corp.

Instrument Line...... Commander class is a new range of instruments engineered to be more practical and highly accurate for process measurement and control, according to announcement in 4-page bulletin.
518B George Kent, Ltd.

Mass Spectrometer...... Type 21-611 portable instrument designed for laboratory and industrial use is covered in a new bulletin 1843. Despite low price, instrument offers many features.
518C Consolidated Electrodynamics.

Measuring Equipment, Flow...... Accurate measurement of flow rate of air and gases. Easy panel or "in-line" mounting, full size range, capacities to 75,000 cfh air, rugged stuffing box. Bulletin SC1022.
42-3h *Selas Corp. of America.

Meter-Relays ...... Contact meter-relays that both indicate and control almost any physical or chemical condition that can be detected electrically are described in a new 40-page catalog.
518D Assembly Products.

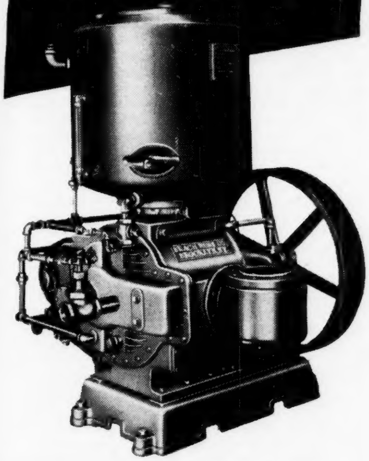
Meters, Liquid...... Industrial metering bulletin 566 has been completely revised to help the process engineer select the best meter-register combination for any job that can be handled with standard meters.
518E Neptune Meter Co.

Meters, Stainless Steel...... New Neptune meter achieves fine-instrument accuracy in the processing of corrosive liquids with complete protection from effects of corrosion. Request Bulletin 94/10 N.
426 *Neptune Meter Co.

Monitoring Systems ...... Detection, recording and warning of airborne particulate radioactivity by complete monitoring systems is described in a new 6-page bulletin AM-57 now available.
518F Nuclear Measurements Corp.

* From advertisement, this issue

THE ANSWER TO YOUR WATER PROBLEM



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Vapor Purge Pumps

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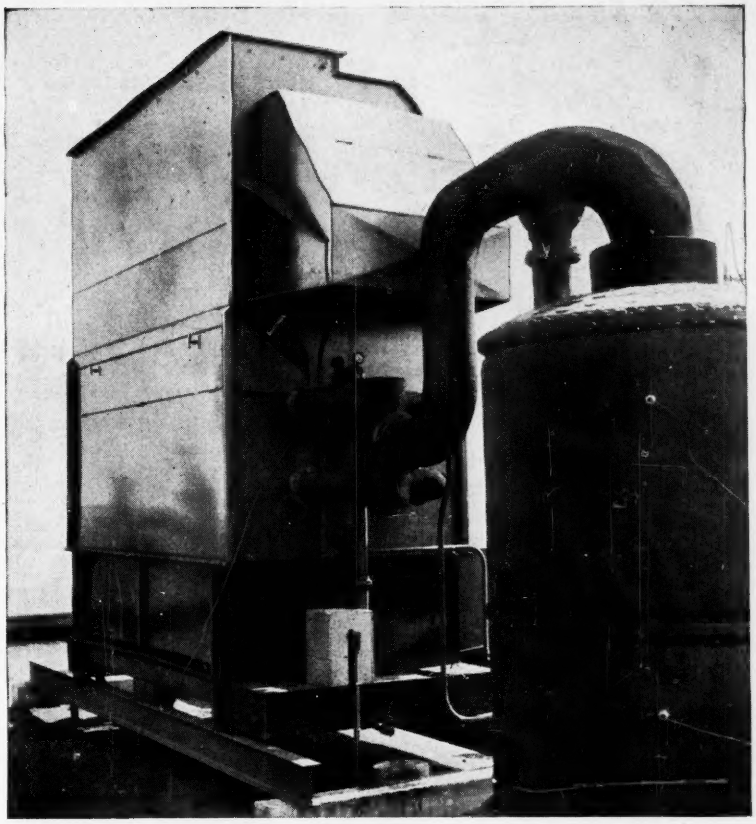

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● NIAGARA *AERO* VAPOR CONDENSERS give sustained full capacity in condensing vapors by evaporative cooling with only nominal use of water. You have no problems of water availability or disposal, or quality, or temperature.

Non-condensibles are effectively separated and subcooled, giving better vacuum pump operation. Liquids and vapors are always held at constant temperatures. Cooling effect is directly proportional to the load. You get uniform distillation products the year round. You get better quality control and higher production. You save power and steam. Capacities up to 30 million BTU.

Write for full information.
Ask for Bulletin 129R.

NIAGARA BLOWER COMPANY
Dept. CE-6, 405 Lexington Ave. New York 17, N. Y.
District Engineers in Principal Cities of U. S. and Canada

Regulator, Oil-Air Ratio......Details on an oil-air ratio regulator are set forth in Data Sheet 722A. Unit delivers the proper oil pressure to correspond to the air pressure going through the burners.
520E Hauck Mfg. Co.

Regulators, Voltage......Bulletin covers Stabiline automatic voltage regulators . . . Type IE and Type EM. Rating chart simplifies selection of the regulator best suited to your need. Request Bulletin S 351.
520F Superior Electric Co.

Sonar Caliper......Capacities of brine wells and LPG storage reservoirs can be determined by converting reflected sound waves into distance with the Sonar Caliper described in a new 4-page bulletin.
520G Dowell, Inc.

Photometer, Pollution......Polluted air, either outdoors or inside can be measured and controlled with a new portable photometer described in Bulletin JM-1000-C. Applications, sensitivities and ranges.
520A Phoenix Precision Instrument.

Process Control, Electronic......Bulletin covers: electronic miniature recorder, Type 150C; electronic recording control station, Type 162; electronic controller, Type 163; etc. Request Catalog 164.
520B Manning, Maxwell & Moore.

Process Control, Pneumatic......New Taylor Transcope Controller is especially suited to short spans of measurement fast and responsive to adjustments, exceptionally adaptable. Bulletin 98278.
86 *Taylor Instrument Co.

Process Control System, Electronic..... An all-electronic system of miniature-type instruments that provides the ultimate in process control, product quality and total economy. Microsen Bulletin.
74-5 Manning, Maxwell & Moore.

Pyrometers......Alnor Pyrotac automatically protects furnaces, kilns and other heating equipment against damage due to excessive temperatures. Easily installed, low-cost reliable. Bulletin 2002.
407 *Illinois Testing Labs.

Pyrometers, Portable......Consistently accurate type 1500 portable pyrometers available in ten scale ranges from 0-400 degrees to 0-3000 degrees F. or centigraded equivalents. Bulletin 4434.
R542 *Illinois Testing Labs.

Recorder, Millivoltmeter......How the portable millivoltmeter recorder is used to survey electrolytic corrosion and deterioration of underground pipe and cables is detailed in Bulletin E1117.
520C Bristol Co.

Recorders, Multi-Point......Permanent recording of as many as 16 points on one chart—at standard recording speeds ranging from 3 to 24 inches per hour—on Wheelco Series 8000 recorders. Bul. F-7955.
402 *Barber-Colman Co.

Regulator, Gas......Complete capacity tables on the 141 and 173 regulators are included for the first time in newly revised bulletin 1024-6 on Rockwell's line of high pressure regulators.
520D Rockwell Mfg. Co

* From advertisement, this issue

Switch, Commutating......Deltaswitch is a unique commutating switch that uses a jet of mercury for a wiper arm. Deltaswitch is a custom engineered unit. Specifications given in Data Sheet S56-09.
521A Norwood Controls.

Switch, Liquid-Level......Technical Bulletin 381-1 describes a new liquid-level switch which utilizes a radioactive material in the sensing element. Information is complete on construction, applications, etc.
521B Robertshaw-Fulton Controls Co.

Thermometer Probe, Resistance...... By utilizing a grid of extremely fine platinum wire welded to platinum lead wires, this probe is capable of operation over the range of from 0 to 1200° C. Bulletin.
521C Arthur C. Ruge Assoc.

Thermometers......"Every Angle" Bi-Metal Thermometers. Three feature: "Every angle" design for installation anywhere, anti-parallax maxivision dial, bi-metal actuation. Details in Bulletin 148.
521D Manning, Maxwell & Moore.

Transducers, Engine-Pressure......For temperature compensated dynamic pressure measurement. Fields of applications: aircraft engines, automotive engines, gas engines, gas turbines, etc. Bulletin A257.
521E Norwood Controls.

Transmitters, Pressure.....Advantages of the "null-balance-vector" principle in pressure and differential pressure transmitters are covered in Folio No. 56-12 and Folio 56-13A which describes these new units.
452 Republic Flow Meters Co.

Pipe, Fittings, Valves

Coupling, Quick-Opening......New Bulletin 270 describes the quick-connect, quick disconnect coupling HK which is first using Teflon seals throughout to pass successful field tests, it is said.
521F Snap-Tite, Inc.

Fittings, Lubrication......Hundreds of fittings for every requirement together with dimensions are found in a new catalog, Form 38-23. Also included are special fittings and accessories.
521G Stewart-Warner Corp.

Fittings, Stainless-Steel....How Speedline fittings offer a new concept in stainless-steel piping is told in a new 24-page bulletin. Contains all the information needed to select and apply fittings.
521H Horace T. Potts Co.

Gaskets......New 48-page catalog on industrial gaskets, mechanical packings, etc. contains recommendation chart, material comparative cost graph, fault elimination chart, and mechanical formulas.
521I Rhopac, Inc.

Hose, "Dacron"-Jacketed......New industrial hose jacketed with 100% "Dacron" polyester fiber is stronger, lighter, easier to handle, and much more flexible than previous types. Manufacturers' names in booklet.
102 *E. I. du Pont de Nemours.

* From advertisement, this issue

LITERATURE . . .

Hose, Flexible......New Teflon flexible hose assemblies described in Bulletin TF-100 have been built for economy and long life in fuel, oil, chemical, oxygen, hydraulic lines and other uses.
522A American Brass Co.

Hose & Tubing, Metal, Flexible....New catalog simplifies selection and ordering of metal hose and tubing for industrial equipment and maintenance applications. Complete details available in Catalog G-560.
87 American Metal Hose Div.

Joints, Expansion......Rubber, neoprene and Teflon-lined expansion joints are fully explained in a recent bulletin that shows construction, sizes and uses. Covers characteristics and limitations of 7 styles.
522B Garlock Packing Co.

Joints, Expansion......Complete line of expansion joints in rubber, neoprene, and Teflon eliminate noise, vibration, and flange breakage in piping. Available for handling any liquid or gas. Folder AD-137.
68-9 *Garlock Packing Co.

Joints, Expansion......New 72 p. catalog covers the design, manufacture and application of the company's line of packless corrugated expansion joints, including three new types. Request Catalog #56.
428 Zallea Bros.

Joints, Expansion Rubber......U. S. Rubber Expansion Joints are resilient, do not become brittle, absorb axial and lateral deflection, insulate against vibration and pump noise. Request catalog.
359 *U. S. Rubber Co.

Joints, Expansion, Rubber......Garlock rubber expansion joints are made from high-grade rubber, combined with plies of sturdy cotton duck and reinforced with steel rings. Full details in Folder AD-137.
361a *U. S. Gasket Co.

Nozzels, Spray......Company makes available on request a completely detailed Catalog which provides valuable data on Spraco Nozzle line. Information on full cone, flat spray & hollow cone types.
510 *Spray Engrg. Co.

Nozzles, Spray......Company provides a 48 p. industrial catalog with full data on thousands of standard and special nozzles—for every type of spraying. Also information on related equipment. Catalog No. 24.
T538 *Spraying Systems Co.

Nozzles, Spray......Monarch's advanced design reduces clogging and guarantees dependable applications to wax fruits, rinse vegetables, dry eggs, powder milk, wash filter cake, etc. Catalog 1.
R547 *Monarch Mfg. Works.

* From advertisement, this issue

Any bulletin or catalog . . . yours for the asking

You can get any publication in this literature listing by circling its key number on the Reader Service Post Card (inside back cover). Replies will reach you direct from the manufacturers.

Outlet Connection......Bulletin CP-1-57 reports details on a new line of easy-to-install branch outlet connections for pipelines, tanks and pressure vessels. The Couplet functions as universal connection.
523A H. K. Porter Co.

Pipe......Request your free copy of this new pipe fabrication team bulletin, called "How Piping is Fabricated." Tells how Flori fabricates its pipe and how they sell this pipe as a team.
109 *Flori Pipe Co.

Pipe, Aluminum......Reynolds aluminum pipe features: lower cost, light weight, strong-seamless, non-rusting, fast installation, flexibility, standard sizes-highest quality. Request Bulletin C3b-10-2560.
85 Reynolds Metals Co.

Pipe Benders......Greenlee No. 884 hydraulic pipe bender bends pipe or conduit 90 degrees with one ram stroke. Handles ½-in. to 2-in. pipe or conduit. Aluminum alloy construction. Bulletin E-217.
B534 *Greenlee Tool Co.

Pipe & Fittings......Luzerne PVC pipe and fittings are light in weight, easy to install with either screwed fittings or welded socket fittings, and economical. Immediate delivery. Details in Bulletin PF-1100.
R526 *Luzerne Rubber Co.

Pipe & Fittings......New technical bulletin describes company's full line of corrorsion-resistant polyvinyl chloride pipe and fittings. Company makes Bulletin No. PF-1200 available upon request.
523B Luzerne Rubber Co.

Pipe & Fittings, Jacketed......Catalog on line of steam jacketed pipe and fittings, either screwed or welded ends, has been revised to include additional sizes with more complete information.
523C Red Jacket Co.

Pipe, Hard Rubber......Heat-resistant nitrile hard rubber pipe handles inorganics at 250-275 deg. F . . . also resists wide range of organic chemicals at room temperature. For details see Bulletin 96-A.
364a *American Hard Rubber Co.

Pipe, Plastic.....General-purpose moderately priced rubber-plastic pipe handles most common chemicals to 170 F . . . except few strong acids & organic solvents. Tough, odorless, tasteless. Bulletin 80.
364d *American Hard Rubber Co.

Pipe, Reinforced Resin......Design, construction and typical applications of Fluoroflex-T pipe (Teflon resin and glass fibre) are discussed in a new 4-page bulletin issued recently by the manufacturer.
523D Resistoflex Corp.

Pipe, Rigid......Ace Parian odorless, tasteless, rigid polyethelene pipe stays tough at sub-zero temperatures. Best chemical resistance of any plastic at room temperature. Request Bulletin 351.
365a *American Hard Rubber Co.

Pipe, Steel......Folder TDC-138 contains two tables. One lists dimensional data for 16 pipe sizes for six weight schedules. Other table covers ASTM, ASME specs. for carbon, alloy, stainless pipe.
523E Babcock & Wilcox Co.

* From advertisement, this issue

Piping Identification......"How to Identify Your Piping System" contains specifications laid down and approved by the ASA in conjunction with the National Safety Council and the ASME.
524A Rust-Oleum Corp.

Piping, Steam-Traced......Installation and perfomance details of the new Unitrace steam-traced extruded aluminum pipe are given in a booklet now available. Cross section of new pipe matches standard pipe.
524B Aluminum Co. of America.

Tubing, Flexible......Hundreds of applications in the steam and Diesel power fields are filled by Penflex flexible tubing. For complete information on product line, request copy of "Flexineering" booklet.
223 *Pa. Flexible Metallic Tubing.

Tubing, Heat Exchanger & Condenser . . . . . .Electric-resistance-welded carbon steel heat exchanger and condenser tubing widely used in process industries, including petroleum refining, etc. Bulletin 412.
153 *Babcock & Wilcox Co.

Tubing, Titanium......Folder TDC-185 presents in detail the size range, tolerances and complete description of the mechanical, physical and working properties of the metal in tubular form.
524C Babcock & Wilcox Co.

Valve Operator, Control......Bulletin describes Microsen Series 181 Valve Operator. Gives features, description, applications, principal of operation, models available, etc. See Bulletin RM211.
524D Manning, Maxwell & Moore

Valve, Plastic Ball......Information about the all PVC Double-Seal ball valve is given in a bulletin now available. This type D88 valve is used with normal or high-impact plastic piping.
524E Jamesbury Corp.

Valve, Y......A new leaflet gives details on new type all-fabricated stainless-steel Y valve with renewable Teflon disk. Vales are fabricated to schedule dimensions to use with schedule pipe.
524F Star Tank & Filter Corp.

Valves......There's an Ace Hard rubber, rubber-lined, or plastic-lined valve for every corrosion application. Diaphragm, gate and check types. Lists chemicals handled in Bulletin CE-52. Request your copy.
364c *American Hard Rubber Co.

Valves, Check......In a new 8-page Bulletin, Form 300, you are shown how to combine Durabla basic check units with any standard pipe fitting to form a complete check valve. Sizes and weights of basic units.
524G Durabla Mfg. Co.

Valves, Control......Super 70 Series control valves offer: accurate response from topworks; greater stability through valve; self-actuating closure with float ring. Details available in Catalog 70-11.
441 Black, Sivalls & Bryson.

Valves, Diaphragm......Neoprene diaphragm on Crane No. 1610 Packless Diaphragm Valves seals the bonnet without crushing and excessive wear. Wide selection of exclusive Crane valves. Request Circular AD-1942.
231 *Crane Co.

* From advertisement, this issue.

Valves, Diaphragm Control......Kieley and Mueller diaphragm control valves have solid, not fabricated design, rugged guide posts, large column, super-finishing. Send for Bulletin CV53 for data.
34 *Kieley & Mueller Inc.

Valves, Drain......offers descriptive information on line of Strahman ram type valves . . . the only drain valves that cannot clog up. Made in any cast metal to meet your requirements. Request Catalog.
L367 *Strahman Valves.

Valves, Explosive........How liquid or gas can be stored indefinitely at pressures up to 5,000 psi. and then released instantaneously is described in new Catalog 5501-XV on the explosive-actuated valve.
525A Conax Corp.

Valves, Fittings & Flanges......Vogt drop forged steel valves, fittings and flanges for oil, steam, water, air, gas and refrigeration services withstands shocks, stresses, corrosion. Request Catalog F-9.
323 *Henry Vogt Machine Co.

Valves & Fittings. Plastic......Illustrated 16-page bulletin on line of PVC valves and fittings includes 4 pages of application tables, cutaway draw- and four data tables. Request your copy.
525B Walworth Co.

Valves, Gate......Stand up perfectly under conditions ranging from 380 psi at 1000°F to 2000 psi at 100°F. Use Chapman List 990 valves for higher pressures. Full details available in Catalog 10.
112 *Chapman Valve Mfg. Co.

Valves, Gate.....Jenkins Ni-Resist cast iron or stainless steel gate valves are designed especially for corrosive services, have good metal-to-metal wearing qualities. Free of copper. Get Bulletin 121.
413 *Jenkins Bros.

Valves, High Pressure....New improved 60,000 p.s.i. valve provides greater operational safety and prevents unsafe use of interchangeable lower pressure fittings. Ask for Bulletin 455 with details.
449 *Autoclave Engineers, Inc.

Valves, High Pressure......Feature Evalthrust ball-bearing yoke, internal streamlining, impactor handwheel, guided stellited disk, integral stellite seat, improved pressure-seal. Condensed Catalog.
110 *Edward Valves.

Valves, Needle......Catalog NV-1 hails the Marsh needle valve as the first throttling and shutoff needle valve suitable for working pressures up to 10,000 psi. which will also operate efficiently at low pressure.
525C Marsh Instrument Co.

Valves, Pinch Type......New Catalog details line of flexible, pinch-type, hose-bodied valves in both Standard and new Superseal, metal-enclosed designs. Major feature—long data section.
525D Farris Flexible Valve Corp.

Valves, Pump......How a line of pump valves has been redesigned to incorporate a new taper-lock stud, self-locking nut and drop-on guard is described in new 8-page bulletin which includes data tables.
525E Durabla Mfg. Co.

* From advertisement, this issue.

Valves, Regulating......External pilot mounting provides simplified maintenance. Trouble shooting is faster, downtime is reduced. For information on wide range of regulating valves, see Bulletin 1005.
447 *Spence Engineering Co.

Valves, Stainless Steel......Cooper Alloy stainless steel valves feature: extra-deep stuffing box, union bonnet joint, retained renewable disc. See "Design Factors in Stainless Steel Valves."
434 *Cooper Alloy Corp.

Process Equipment

Adsorbers, Vapor......Continuously remove hydrocarbon vapors, liquid hydrocarbons, water hydrocarbon emulsions, and dirt from compressed air and process gases. Full details in Bulletin SC1047.
42-3e *Selas Corp. of America.

Airlocks, Rotary......Rotary Airlock Feeders for low pressure dust control systems, higher pressure dust control or pneumatic conveying systems. Complete specifications and data in Bulletin P-55.
506 *Prater Pulverizer Co.

Boiler-Cleaning Equipment....Vacuum cleaning equipment for keeping boilers clean is highlighted in a 4-page bulletin issued recently. Both stationary and portable units are discussed.
526A Spencer Turbine Co.

Centrifugals......Batch-Master offers choice of perforate and imperforate baskets . . . corrosion-resistant materials . . . manual unloader if desired. Further information available in Bulletin TC-14-56.
376 *Tolhurst Centrifugals.

Collectors, Centrifugal......Two new centrifugal collector designs are described in detail in a new fully illustrated folder. Also included are complete specifications for 41 collector sizes.
526B Kirk & Blum Mfg. Co.

Collectors, Sludge......Circulating Collector accomplishes positive movement of sludge, along the most direct path to the draw-off, in the shortest time. Company gives complete information in Book 1982.
526C Link-Belt Co.

Crushers, Gyratory......New Bulletin 1126 contains illustrations, cross-section dwgs, complete specifications and features of Traylor TC gyratory crushers. Tables of sizes and approximate capacities.
526D Traylor Engrg. & Mfg. Co.

* From advertisement, this issue

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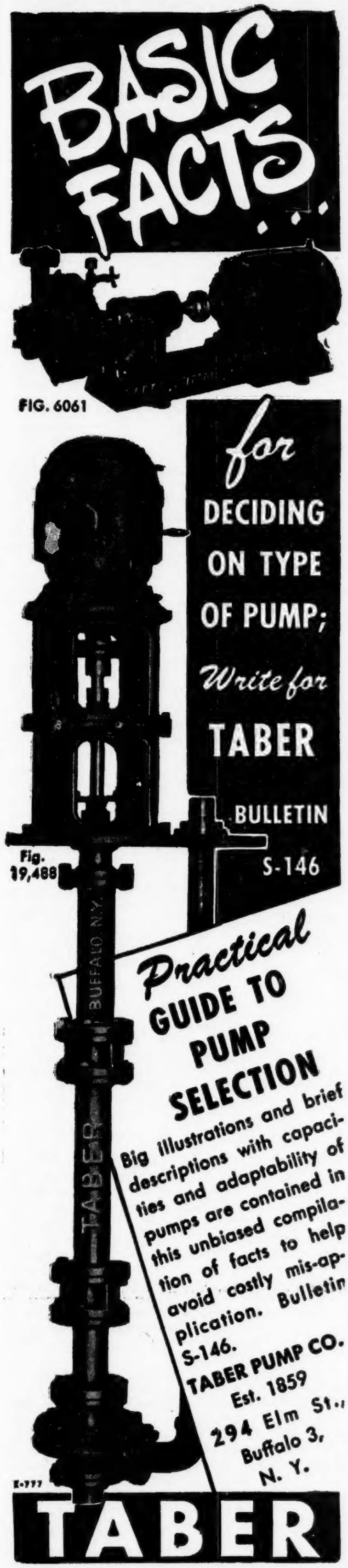

Crushers, Jaw......Cast, steel, frame, manganese jaw and check plates. Lage diameter shafts reduce shaft deflection and thus increase life of roller bearings in bumper. Full details in Bulletin C12-B12.
516c *Denver Equipment Co.

Crushing & Grinding......Sturtevant laboratory machines can expose all crushing or grinding parts for thorough cleanouts in a matter of seconds because of hinged access doors. Ask for Bulletin 067.
414 *Sturtevant Mill Co.

Dehydrators.....Continuous, automatic drying of compressed air, process gases and liquids. Gases include carbon dioxide, carbon monoxide, hydrocarbons, hydrogen, inert gases and oxygen. Bulletin SC1013.
42-3g Selas Corp. of America.

Demineralizers, Water......All-plastic water demineralizers that operate by ion exchange are described in a new bulletin. Units are virtually indestructable and avoid internal corrosion.
527A Enley Products, Inc.

Digester, Continuous......Bulletin PC-20 describes and illustrates construction and operation of the Pandia Chemi-Pulper continuous digester for pulp mills. Sizes and capacities are included.
527B Black-Clawson Co.

Dryers......Instrument air dryers are dependable, require very little attention. They are used in pipe lines, natural gasoline plants, and refineries for air fed to instruments and motors. Bul. 223-A.
218 *Pittsburgh Lectrodryer Div.

Dryers......Full line pressure reactivation, purging eliminated, longer absorbent life, no moving parts, simple design, all air or gas entering dried without loss. Complete details in Bulletin 16.0.81.
384 *J. F. Pritchard & Co.

Dryers......Offer a variety of dryer models to meet all problems. Designed to dry air, gases or liquids to sub-zero dew points at low cost. Constructed of quality materials. Details in Bulletin D-100.
409 *C. M. Kemp Mfg. Co.

Dryers......Davenport makes pressing, drying and cooling equipment, continuous dewatering presses, rotary dryers (steam tube, hot air, and direct fire), atmospheric drum dryers, etc. Catalog "A".
B535 *Davenport Machine & Foundry Corp.

Drying Equipment......Your product is dried, ground, classified, cooled and conveyed to storage in a single integrated unit-an Imp Mill, a Roller Mill, or a Cage Mill. Send for Raymond Bul. No. 82.
232 *Combustion Engineering Inc.

Dust Collectors......In almost every type of industry . . . users have found high efficiency, simplicity & economy of Dustube collectors a difficult combination to equal for top performance. Bulletin No. 372C.
80 *Wheelbrator Corp.

Dust Collectors......Separating efficiencies up to 98.9% on foundry shakeout dust possible, practical and continuous with Hydro-Filter. Turbulent area assures positive dust collection. Bul. 55.
L539 *Dust Collector Corp.

* From advertisement, this issue

LITERATURE . . .

Dust Control......A 4-page report on "How to Control Dust and Save Money in the Manufacture of Building Materials" contains case histories on ready-mix concrete, roofing products, cement wallboard.
528A Wheelabrator Corp.

Feeder, Chemical......A new air or water operated diaphragm feeder, model 19130, designed to handle concentrated chemicals more safely is described in new bulletin 1913 now available.
528B Proportioneers, Inc.

Filter, Air......New line of Roll-O-Vent air filters is described in new Bulletin 780. Glass-fiber filter media fed and recovered by spools operates automatically to allow once-a-year maintenance.
528C American Air Filter Co.

Filter Paper......E&D filter paper as a cover may be indicated if your filter medium is blinding or clogging. Will recommend proper grade for use and send samples for testing. "Filtration Analysis Report."
512 *Eaton-Dikeman Co.

Filter, Sweetland Pressure......Revised, 4-page Bulletin 7400 tells you about the design, materials of construction, operation and advantages of the Sweetland pressure filter for batch operation.
528D Dorr-Oliver.

Filter Tubes......Bulletin AFD50-1B gives you the details on how Honeycomb filter tubes micronically clarify liquid chemicals at various temperatures. Tubes are manufactured in natural and synthetic fiber.
528E Commercial Filters Corp.

Filters......Fulflo Filters for microscopic clarification of industrial liquids and various gasses with honeycomb filter tubes. Tubes available in nylon, orlon, dynel, acetate, glass. Catalog PM-200A.
528F Commercial Filters Corp.

Filters, Air......According to Bulletin 120, Aerosolve filters now have interchangeable cartridges to permit changing to high or lower efficiencies to meet changing conditions and control cost.
528G Cambridge Filter Corp.

Filters, Air......Type N Roto-Clone, a hydrostatic precipitator, collects heavy dust loadings of all particle sizes with highest efficiency and lowest maintenance costs. Request Bulletin 277.
122 *American Air Filter Co.

Filters, Corrosive Liquids......Adams Filters in several different metals, lined with rubber or lead when necessary, solve problems of temperature control, safety of personnel. Request Bulletin 431.
327a *R. P. Adams Co.

Filters, Disc......Special patented design of segments in filters use both gravity and vacuum to give a drier filter cake. Drainage is complete and positive with no blow-back. Details in Bulletin FG-B1.
516d *Denver Equipment Co.

Filters, Horizontal Pressure......Filters with many convenience features: quick opening door, shakers for cleaning, equal size leaves. Can be automated for continuous operation. Request Bulletin NH-122.
6-7c *Industrial Filter & Pump.

* From advertisement, this issue

Filters, Liquid......Dollinger liquid filters can filter practically any liquid successfully, regardless of temperature, pressure, or efficiency desired. Filter bodies in steel, monel, etc. Bul. 300.
446 *Dollinger Corp.

Filters, Porcelain ...... Micro-porous porcelain filters are used for clarification, polishing, cold sterilization of pharmaceuticals, biologicals, and fine chemicals. Send for details in Bulletin SC1051.
42-3i *Selas Corp. of America.

Filters, Tubular......Excellent for polishing, as a trap filter or scavenger. Operation and cleaning is greatly simplified by inside-out flow system. For complete details, request Bulletin TS-160.
6-7d *Industrial Filter & Pump.

Filters, Vacuum, Rotary, Continuous ......The Original String Discharge Filter is only one of many types of FEinc continuous rotary vacuum filters available ... custom-made at standard costs. Bulletins.
135 *Filtration Engineers.

Filters, Vertical......Standard or specially engineered models for any filtration process. Available with various rapid cleaning features and fully automatic controls. Request Bulletins 111 and 114-1155.
6-7b *Industrial Filter & Pump.

Filters, Water......Where high quality process water is needed, diatomite filters will provide an effluent second only to distilled water. Bulletin 651 covers this type of industrial water filter.
327b *R. P. Adams Co.

Filtration Equipment .... Sperry makes available a catalog complete with charts, tables, and diagrams to help in the operation, maintenance and selection of filtration equipment. See Filtration Catalog.
R543 *D. R. Sperry & Co.

Flotation......More large plants are installing "Sub-A's" for entire flotation job, because they give maximum recovery at a low cost per ton. Simplified continuous operating. Details in Bulletin F10-B81.
516e *Denver Equipment Co.

Fluo-Chlorinator......How the Model F-1400 Fluo-Chlorinator adds controllable quantities of fluoride and chlorine solution to potable water is explained in new Catalg 70F140. Request your copy now.
529A Fischer & Porter Co.

Foam Machine......Now polyurethane foams of any formulation can be produced at amazingly low investment with Klauder Williams foam machines according to a new bulletin that describes these units.
529B Gabriel Williams Co.

Gamma Reference Sources......Available as standards for radioisotope users, these sources have known gamma-ray energies and intensities which are depicted on a 2-page leaflet now available.
529C Baird-Atomic, Inc.

Generators, Inert Gas......New Sub-X inert gas generator uses submerged exhaust of combustion products, allows river water or other low-cost water supply as coolant. Compact, economical. Bul. 114.
548 *Thermal Research & Engrg.

* From advertisement, this issue

Lubrication Equipment . . . . . . Complete catalog of Alemite lubrication equipment includes fast, efficient heavy-duty Alemite hand guns, with 10,000 lbs. pressure, long-operating handle, clean filling.
103 *Stewart-Warner Corp.

Metallizing, Repair......How you can spray molten metals onto a base surface to build up worn mechanical equipment, apply hard-wearing surfaces, correct surface defects is told in new bulletin.
530A Metalweld, Inc.

Mills, Ball......A steel-head ball mill will suit your particular need. Five types of discharge trunnions. All-steel construction. Low initial cost due to quantity production. Details in Bulletin B2-B13.
516b *Denver Equipment Co.

Mixers......Exclusive counter-rotating impellers produce finer, faster mixing. Interchangeable heads, new precision face type magnetic seals for complete and effective shaft seal. Brochure 564-2.
388 *Gabb Special Products Inc.

Mixers......Company makes available Confidential Mixing Data Sheet. Helpful checklist enables you to develop a complete technical description of agitation required for your process. Bulletin B-107.
321h *Mixing Equipment Co.

Mixers......Describes Super Agitators and Mixers. Patented stand-pipe around propeller shaft assures positive agitation. Patented wearing plate prevents sand-up on shut-down. Request Bulletin A2-B4.
516a *Denver Equipment Co.

Mixers, Chemical......Bulletin covers Shear-Flow Mixer; for mixing, homogenizing or dispersing; up to five times faster; counter-rotating impellers; reduces agglomerates and particle size; no operating torque.
530B Gabb Special Products.

Mixers, Laboratory......You get as much as 20 years' service from a Lightnin Laboratory Mixer. Can run Model F at any speed up to 1600 RPM. Four other models to choose from. Bulletin B-112.
321e *Mixing Equipment Co.

Mixers, Portable......Use in industry reduces costs, saves time, labor and secures better and more refined products. Catalog includes data on construction, dimensions, specifications, etc. Bulletin B-108.
321c *Mixing Equipment Co.

Mixers, Portable......Versatile Eastern portable mixers can be quickly shifted from task to task to allow one mixer to serve many needs. Available from 1/20 to 5 H.P. Ask for Eastern Bulletin 520-A.
BR539 *Eastern Industries Inc.

Mixers, Side Entering......Furnishes detailed information on features, typical applications, mechanical design, maintenance, shaft seals, methods of installation, etc., in Catalog B-104.
321d *Mixing Equipment Co.

Mixers, Top Entering......Illustrated 32 p. Catalog includes advantages, typical installations, mechanical description, construction information, dimensions and selection tables, etc. Catalog B-102.
321a *Mixing Equipment Co.

* From advertisement, this issue.

Mixers, Top Entering......Makes available pertinent information on top-entering mixers (propeller type) . . . for closed tanks, pressure & vacuum . . . for open & loose-covered tanks. Catalog B-103.
321b *Mixing Equipment Co.

Mixers, Tripe Action......Triple action mixers give uniform blending and mixing in 2 to 7 minutes with 99% thorough distribution of minor additives. Nylon seals between tub and shaft. Color Bulletin.
187 * Strong-Scott Mfg. Co.

Mixing Equipment......Company offers Side Entering Propeller Mixer Bul., RDC Extraction Column Bul., Minerals Processing Bul., and General Turbo-Mixer Bul. New series of Turbo-Mixers in standard sizes.
354a *General Amer. Transport.

Pipe Hangers, Supports, & Vibration Eliminators......Complete line of standard and custom-engineered pipe hangers, supports, and vibration eliminators. Each a complete packaged unit. Cat. No. 54.
120c *Blaw-Knox Co.

Process Equipment......32 p. bulletin covers all Allis-Chalmers equipment for the process industries. This bulletin, as well as literature covering specific equipment lines, is available. Bulletin 25C6177.
44-5 *Allis-Chalmers Mfg. Co.

Processing Equipment, Impervious Graphite . . . . . Bulletin shows a typical drawing or illustration of each type of equipment, lists the standard models available. Company gives details in Bulletin No. 249.
390 *Falls Industries.

Pulleys, Electromagnetic......Stearns manufactures electromagnetic pulleys in sizes to meet your requirements for positive tramp iron protection on conveyor lines. Send for your copy of Bulletin 303-DB.
450b *Stearns Magnetic Products.

Pulleys, Magnetic......Stearns builds a complete line of engineered magnetic pulleys for positive tramp iron protection on conveyor lines in any processing industry. Request your Bulletin 350-CB.
450a *Stearns Magnetic Products

Pulverizers......Pulverizers for Chemical and allied industries. Uniform pulverizing to needle point and microscopic finenesses. Laboratory models designed for experimental work. Request Bulletin 242.
531A *Gruendler Crusher & Pulv.

Purifiers, Air, Gas & Steam......In Bulletin 801 are listed principal applications of Anderson purifiers. New information covers improved types of internal units installed inside vessels, etc.
531B V. D. Anderson Co.

* From advertisement, this issue.

Any bulletin or catalog . . . yours for the asking

You can get any publication in this literature listing by circling its key number on the Reader Service Post Card (inside back cover). Replies will reach you direct from the manufacturers.

Reclaimer Systems, Oil......A simple economical and efficient method of restoring contaminated lubricating and sealing oil to the full value of new oil. Offers details on reclaimers in Bulletin R-160.
379 *Hilliard Corp.

Reducers, Speed......Bulletin 1105 combines complete information on the Falk line of concentric shaft and right-angle speed reducers for applications up to 140 hp. Selection tables give info at glance.
532A Falk Corp.

Reducers, Speed......Complete details on an improved and extensive line of speed reducers are presented in Bulletin CD-218. Use of double-enveloping worm gearing provides more load-carrying capacity.
532B Michigan Tool Co.

Samplers, Automatic......Heavy duty units, extra rigid track and ball-bearing wheels assure positive travel and timing of sample cutter. Available in stainless steel. Full details available in Bulletin S1-B4.
516g *Denver Equipment Co.

Screens......"Symons" rod deck screens offer low screening cost, big capacity, for wet and sticky ores, minimum maintenance. Bulletin 94C covers economy, capacity, vibrator, housing and screen deck.
532C Nordberg Mfg. Co.

Screens, Vibrating . . . . . . Gives fast, clean separation without blinding. Even, smooth flow of material because of patented "true-circle" eccentric action. Full details available in Bulletin S3-B11.
516h *Denver Equipment Co.

Separators, Liquid . . . . . . Continuously separate emulsions in steam distillations, solvent extractions, organic reactions. For dewatering of solvents and hydrocarbons, recovery of liquids. Bulletin SC1044.
42-3f *Selas Corp. of America.

Separators, Liquid-Gas . . . . . . Selas Liqui-Jectors protect air, gas, and steam systems and pneumatically operated instruments from effects of entrained water, oil, water-oil, water-oil and dirt. Bulletin S1052.
42-3d *Selas Corp. of America.

Spectrophotometers . . . . . . New KM-I table-top double-beam infrared recording spectrophotometer designed especially for routine analyses. Many accessories available, new smaller dimensions. Bul. IR-448.
514 *Baird-Atomic, Inc.

Tank Vents & Flame Arrestors...... BS&B tank vents, flame arrestors, and arrestor vents combining the features of the above are described in Catalog 76-16. Request your copy now.
373 Black, Sivalls, & Bryson

Thickeners......Enclosed, running-in-oil tread motion. Patented spiral rakes move settled solids to center discharge with continuous motion, rapid removal of solids tends to eliminate overload. Bul. T5-B5.
516i *Denver Equipment Co.

Viscosity Recording . . . . . . Process mounted viscometer, the Viscometran, is now used for end point determination and continuous "in-process" viscosity recording. Dependable, easily cleaned. New data sheet.
509 *Brookfield Engineering Labs.

* From advertisement, this issue

Water Treatment......Company offers folder on water treatment: importance of water; water treatment by ion exchange; research facilities; types of equipment; terminology; modernization. Request copy.
534A H. M. Mueller Corp.

Water & Waste Treaters......Infilco's complete line of equipment and processes for treating municipal and industrial water, sewage and industrial waste are covered in Bulletin 80 now available.
534B Infilco, Inc.

Welding Repair......New bulletin tells how various welding processes are used to repair broken or worn machinery, structures, storage tanks and material-handling equipment. Repairs follow ASME code.
534C Metalweld, Inc.

Wire Cloth......80 p. catalog describes company's facilities for fabricating wire cloth parts. Wire cloth parts for screening, filtering and special uses. Provides useful metallurical data. Request your copy.
372 *Cambridge Wire Cloth Co.

Pumps, Blowers, Compressors

Blowers, Centrifugal ...... De Laval makes single stage blowers as well as a complete line of equipment for all refinery services, including multi-stage compressors and turbines. Send for copy of Bulletin 0504.
432 *De Laval Steam Turbine Co.

Compressors......Describes Allis-Chalmers single and two-stage vane type compressors for shop air, gas handling, drilling and numerous other applications. Bulletin Nos. 16B8244 and 16B8126.
133 *Allis-Chalmers Mfg. Co.

Fans, Exhaust......Exhaust Fumes from Corrosive Chemicals deals with the extensive and costly problems of corrosive fumes and atmospheres. Offers tips on Heil-designed air-moving equipment.
534D Heil Process Equipment Corp.

Pump, Controlled Volume......Complete specifications and dimensions for a new controlled volume barrel pump are offered in new Bulletin 1256. Pump meters and pumps toxic or corrosive chemicals from drums.
534E Milton Roy Co.

Pumps......A 64-page catalog covers the complete Waukesha line of positive-displacement sanitary and corrosion-resistant pumps. Instructions for estimating requirements, operating and servicing.
534F Waukesha Foundry Co.

Pumps......Available in aluminum, bronze, stainless steel, Hastelloy and titanium, Aldrich fluid ends handle all types of liquids—nitric acid, caustic solutions, fatty acids, etc. Details in Data Sheet 100.
436 *Aldrich Pump Co.

Pumps ...... Rubber permanently bonded to the impeller and all liquid passages prevents the corrosion that could quickly put an ordinary metal pump out of action. Details in Bulletin 982.
94e *Buffalo Pumps.

* From advertisement, this issue

Pumps . . . . . . Ingersoll-Rand motor-pumps have well-balanced impellers and precision machined parts help provide peak performance and smooth operation on every job. Request latest Motor pump Catalog.
387 *Ingersoll-Rand.

Pumps......"How to Solve Pumping Problems" presents a general explanation of rotary gear pumps, factors of pumping problems, sample problems and technical data. Full details in Form 3060.
380 Geo. D. Roper Corp.

Pumps......Practical Guide to Pump Selection—illustrations & descriptions with capacities & adaptability of pumps contained in compilation of facts to help avoid costly misapplication. Bulletin S-146.
L527 *Taber Pump Co.

Pumps, Acid . . . . . . Mighty midget for pumping acids. Jabsco neoprene-impeller pump made of Ace hard rubber outlasts, out-pumps anything in its pressure, size and price class. Full details in Bulletin 97-A.
364b *American Hard Rubber Co.

Pumps, Acid......80-gpm. centrifugal pump with hard rubber casing and impeller, Hastelloy C shaft. Handles nearly all corrosives. Mechanically simple, trouble-free. For details, request Bulletin CE-55.
365c *American Hard Rubber Co.

Pumps, Boiler Feed......Type RR two-stage and four-stage pumps have efficient, balanced impellers, oversize bearings and shafts, rugged casings with simply formed water passages. See Bulletin 980.
94b *Buffalo Pumps.

Pumps, Centrifugal......New type SZ corrosion resistant single-stage non-priming centrifugal pump able to handle large quantities of air or gases mixed with the liquid. Request Bulletin D-3.
183 *LaBour Co.

Pumps, Centrifugal......Choice of mechanical seals—or packing—with Standard End Suction Centrifugal pumps. Easily convert from one to the other using standard stock parts. Bulletin W-300-B4B.
22-3 *Worthington Corp.

Pumps, Centrifugal . . . . . . Illustrated reference describes line of SSV centrifugal pumps. Includes details of construction of the various sizes available, operating advantages for users, etc. Bulletin No. 107.
L542 *Frederick Iron & Steel.

Pumps, Chemical......Offer features that make them rugged, dependable, long-lived pumps for handling corrosive liquids. In 9 sizes providing capacities up to 720 gpm & heads up to 200 ft. Bulletin 725.4.
517 *Goulds Pumps.

Pumps, Corrosion Resistant......Manual CE-55 helps you select the correct corrosion-resistant pump for any application up to 350 gpm. Comparative data are shown for four types of pumps.
535A American Hard Rubber Co.

Pumps, Double Suction . . . . . . Hydraulically balanced, efficient and durable, in sizes to deliver from 10 to 14,000 gpm for circulating, air conditioning, other plant services. Details in Bulletin 955.
94a *Buffalo Pumps.

* From advertisement, this issue

LITERATURE . . .

Pumps, High Vacuum ...... Catalog covers: industrial and scientific applications, types of vacuum systems, operating mechanism, vibration elimination, gas ballast, discharge valves, etc. Catalog 425A.
536A — Kinney Mfg. Div.

Pumps, High Vacuum ...... Kinney high vacuum pumps and high vacuum systems, including mechanical booster pumps and oil sealed mechanical pumps, increase production and lower costs. Latest literature.
339 — *Kinney Mfg. Div.

Pumps, Liquefied Gas ...... Special line of pumps handle liquid oxygen, liquid nitrogen and other gases which can only be liquefied at very low temperatures. Request your copy of Bulletin 203-7.
401 — *Lawrence Pumps Inc.

Pumps, Paper Stock ...... Handling high consistency liquids — save money and trouble with non-clogging paper stock pumps. Available in alloys or rubber-lined for corrosive and abrasive liquids. Bulletin 953.
94c — *Buffalo Pumps.

Pumps, Process ...... Peerless type DL & DM chemical process pumps feature: accessibility, durability, serviceability, interchangeability, reliability and availability. For complete details, see Bulletin B-1608.
442 — *Peerless Pump Div.

Pumps, Sand ...... Rubber lined sand pumps lower pumping costs 30% to 70% due to simple design and accuracy of rubber parts which increase efficiency 1½ to 3 times over other sand pumps. Bul. P9-B8.
516f — *Denver Equipment Co.

Pumps, Sanitary ...... Offers 18 new features: heavier shaft construction . . . Twin O-Ring Seal that positively prevents product leakage or intake of air . . . reversible sleeve to save shaft wear. 1957 Catalog.
370 — Waukesha Foundry Co.

Pumps, Stock ...... Four bulletins cover Warren stock pumps for pulp and paper mills. These bulletins are all revised. For complete details, see Bulletin 231, Bulletin 234, Bulletin 235, Bulletin 243.
536B — Warren Pumps Inc.

Pumps, Truck ...... Viking truck pumps save time and money when loading and unloading liquids or semi-solids. Powered from the truck, equipped with integral relief valves. Catalogs Gc and SP377c.
L545 — *Viking Pump Co.

Pumps, Vacuum ...... Stokes Vacuum Calculator simplifies calculation of pump performance and selection of pump size for specific applications. Full story on Microvac design features in Catalog No. 752.
454a — *F. J. Stokes Corp.

Pumps, Vacuum ...... Stokes Corp. offers valuable advice, free, in Booklet 755. "How to Care for Your Vacuum Pump" and manufactures highly efficient, compact, easily maintained, low-cost Microvac pumps.
454b — *F. J. Stokes Corp.

Pumps, Vertical Turbine ...... Deming Vertical Turbine Pumps offer many cost-saving features and advantages, can pay for their cost in a year or less where municipal water rates are high. Bulletin 4700.
403 — *Deming Co.

* From advertisement, this issue.

LITERATURE . . .

Ventilator, Roof......Descriptions together with dimensions and capacities are given in Bulletin 550 for the centrilator, a centrifugal type roof ventilator with an exclusive jet Siphon feature.
537A Clarage Fan Co.

Ventilators, Roof......Centrifugal type power roof ventilators are stable, highly efficient, quiet, easily installed, suited to installations with and without ductwork and hoods. Write for Bulletin 550.
88 *Clarage Fan Co.

Services, Processes, Misc.

Analytical Instruments......16 p. catalog describes line of infrared and ultraviolet spectrophotometers, monochromators, flame photometers, vapor fractometers, accessories and components.
537B Perkin-Elmer Corp.

Catalytic Cracker......"Model IV Fluid Catalytic Cracking" describes a continuous, flexible process for converting gas oils and deasphalted stocks to high octane motor gasoline and other distillate products.
537C Esso Research & Eng. Co.

Construction, Process Plant Facilities......Design, engineering, construction of hydrocarbon processing plants, gas producing plants, chemical plants, high-grade specialty catalysts. Brochure G-306.
2 *Girdler Co.

Eye Savers......Booklet gives advantages of modern plastics for safer, low cost eye protection. Eye savers methyl methacrylate is cast optically correct, not molded. Full details in Bulletin No. 200.
537D Watchemoket Optical Co.

Fire Extinguishers......For information on dry chemical, carbon dioxide, and wet chemical fire extinguishers write in for Kiddie's P-8 catalog. Easy to use, fast action, portable, different sizes.
507 *Walter Kidde & Co.

Fire Protection Systems ...... Automatic fog system protects you around the clock, sounding alarms & putting water to work instantly whenever needed. "Fire Can Destroy Your Business".
120b *Blaw-Knox Co.

Laboratory Equipment......Catalog 79, 8 p., describes a line of jar rolling machines for production and laboratory wet or dry grinding, pulverizing and mixing of chemicals, colors, pigments.
537E Abbe Engineering Co.

Laboratory Equipment ......"What's New for the Laboratory," 16 p. booklet, describes stainless steel vacuum and pressure filters, flask heaters, molecular stills, pipettes, flexible heating tapes.
537F Scientific Glass App. Co.

Laboratory Equipment......8 p. leaflet, "New Apparatus and Equipment for the Laboratory," pictures and describes such equipment as microprojectors, refractometers, vacuum pumps, accessories.
537G Wilkens-Anderson Co.

*From advertisement, this issue.

Laboratory Instruments ...... Bulletin 2161 describes the use of a softening point kit and a heat distortion tester for polyethylene samples. Suggests modifications for tester use on other plastics.
538A American Instrument Co.

Laboratory Instruments......4 p. brochure describes new Model 220 industrial gas chromatograph. Flow diagram show how continuous sampling for automatic analysis can be accomplished.
538B Beckman Instruments, Inc.

Molecular Models......4 p. leaflet pictures and describes model sets used for construction of accurate three-dimensional representations of molecular structures. Specifications chart covers set's elements.
538C Arthur F. Smith Co.

Nuclear Radiation......Brochure describes service for radiation testing of materials, radiation effects and damage evaluations. Includes information on use of nuclear radiation in industry.
538D Radiation Applications Inc.

Production Facilities......Comprehensive production facilities available for contract work: manufacturing facilities, experienced personnel, flexibility, dependability. Foundry, metal working, etc. Bulletin.
538E Troy Engine & Machine Co.

Testing, Laboratory......Testing laboratory facilities for complete batch or pilot tests. Ample test facilities for investigations on crushing, grinding, mixing, classification, separation, etc. Bulletin T4-B15.
516j *Denver Equipment Co.

Water Treatment......Technical paper No. 134, "Biological Fouling in Cooling Water Systems," discusses common problems of slime and algae and selection of control agents and the proper toxicant.
538F Betz Laboratories, Inc.

Water Treatment......Technical paper No. 135, "Conductivity Vs. Sodium By Flame Spectrophotometer in Steam-Purity Studies," presents results of extensive laboratory and plant work.
538G Betz Laboratories, Inc.

Zirconia Ware ...... Properties and characteristics of stabilized zirconia ware are described. Includes comprehensive refractory comparison chart on zirconia. Lists types of crucibles, tubing, boats available.
538H Laboratory Equipment Corp.

*From advertisement, this issue

For the latest developments in **Chemicals** **Equipment** **Processes** you'll find our "Guide To Technical Literature" right up your alley. You can get any bulletin or catalog in this listing . . . and fast. Simply circle the item's number on the Reader Service Post Card and mail.

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Chemicals

INDEX

C. J. ROHRBACH

Equipment

PRODUCTS . . .

PRODUCTS . . .

PRODUCTS . . .

PRODUCTS . . .

PRODUCTS . . .

PRODUCTS . . .

Services

READER SERVICE . . .
INDEX OF

Month after month you'll find industry's most progressive firms among our ad pages.

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